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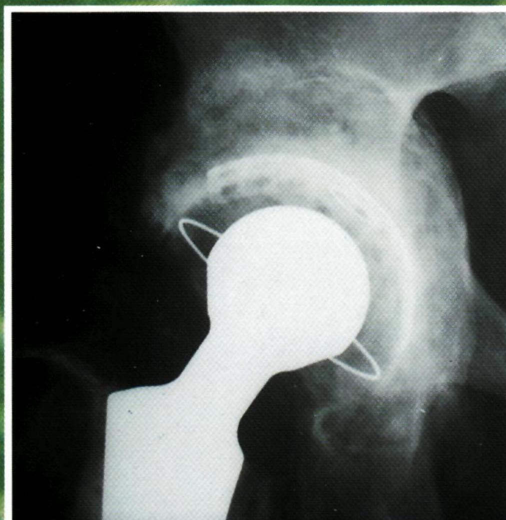
Acetabular reconstruction with impacted morsellized cancellous bone grafts in cemented revision hip arthroplasty



J.W. Schimmel

ACETABULAR RECONSTRUCTION WITH IMPACTED MORSELLIZED CANCELLOUS BONE GRAFTS IN CEMENTED REVISION HIP ARTHROPLASTY

ACETABULAR RECONSTRUCTION WITH IMPACTED MORSELLIZED CANCELLOUS BONE GRAFTS IN CEMENTED REVISION HIP ARTHROPLASTY

een wetenschappelijke proeve op het gebied
van de Medische Wetenschappen

PROEFSCHRIFT

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de Katholieke Universiteit Nijmegen,
volgens besluit van het College van Decanen
in het openbaar te verdedigen
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Aan mijn ouders
Voor Isa, Cecile en Feiko

Contents

CHAPTER 1

General introduction and purpose of the study

Low friction arthroplasty of the hip joint is now without doubt one of the most successful major orthopaedic operations (Charnley 1979) Most patients are satisfied with the result and grateful for the relief of pain and increased quality of life In the last decades, much research has been done and progress has been made regarding cemented and cementless implant fixation (Harris 1992) This has led to optimism among orthopaedic surgeons and a trend to perform total hip arthroplasty at still younger ages can be observed However, experience teaches that the durability of every reconstruction remains limited and to some extent unpredictable (Coventry 1992, Muller 1992) Both cemented and cementless implants have their disadvantages and it can not be concluded from many follow-up studies that one technique is superior to the other (Ahnfelt et al 1990, Beckenbaugh et al 1978, Olsson et al. 1981, Sutherland et al 1982, Wroblewski 1986, Wilson-Mac Donald et al 1989, Huiskes 1993) As the key to long term success has still not been found, the central role of particle debris in the loosening process, next to mechanical factors and the surgeon's expertise, is established (Willert et al 1990, Howie et al 1988, Howie et al 1990, Schmalzried et al 1992, Johansson et al 1987, Huiskes 1993) The disadvantage of the increasing number of hip joint replacements and the decreasing age at primary operation is the growing number of loosened implants encountered in orthopaedic practice As many areas of controversy exist about primary implant fixation, even more uncertainties exist about the best way to revise a loosened implant The key problem in revision surgery is how to handle the bone loss (Amstutz 1982, Johnston 1986, Marti et al 1990, Fuchs et al 1988, Emerson et al 1989, Oakeshott et al 1987, Samuelson et al 1988) Some facts about revision hip surgery are clear It is a time consuming and difficult operation with more complications, longer hospital stays and lesser durablity of the reconstruction The revision will never equal a primary implantation

The use of bone allografts in orthopaedic practice has been introduced nearly half a century ago and was gradually accepted It was a logical step to reconstruct bone stock deficiency around a loosened implant with bone allografts Encouraged by reports about successful bone grafting procedures for protrusio acetabuli in primary hip replacements (Hastings and Parker 1975, McCollum et al 1980), the Orthopaedic Department of the University Hospital Nijmegen started to reconstruct acetabular defects with morsellized cancellous allografts in revision hip surgery in 1979 (Slooff et al 1984) However, basic research about the behaviour of bone grafts around implants was completely lacking and therefore it was decided in 1990 to set up animal experiments to investigate histological and biomechanical characteristics, together with a radiographic follow-up study of the available patient material

The following questions are discussed in this study
- Can morsellized cancellous allografts be used to restore acetabular bone stock deficiency in combination with a cemented cup?
- Are there differences in incorporation capacity and cup fixation parameters regarding type of defect and primary diagnosis?
- Are there differences in the behaviour of autografts and allografts?
- Does incorporation time depend on the amount of bone graft used?
- What is the histological sequence of events during the incorporation proces?
- What is the initial stability of the implant and its course in time? Is stability influenced by graft incorporation?
- Are the outcomes of the animal experiment consistent with the radiographic midterm follow-up study in patients?

Chapter 2 of this thesis presents a review of the literature about acetabular bone stock deficiency in total hip replacement Chapter 3 describes a histological study of acetabular allografts in the goat Chapter 4 deals with the mechanical stability of acetabular reconstructions in the same animal model and in chapter 5 a retrospective radiological study is described of the patient material Chapter 6 is a general discussion with final conclusions

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CHAPTER 2

Acetabular reconstruction with bone grafts in revision hip arthroplasty: a review of the literature

2.1 History of bone allografting

The legend called "the miracle of the black leg" is considered the first known allograft procedure (Mankin et al 1983) The twin physicians Cosmos and Damian, living in the third century, performed many unusual medical feats, but their greatest miracle was the resection of a man's leg because of a tumour and replacing it with the lower limb of a Moor who had just died

In more recent history the first bone allograft implantation was done by MacEwen (1881) He resected a part of the humerus of a 4-year old boy and replaced it by a tibia allograft of a child with rickets Bone transplantation at that time was not an accepted technique, but an experiment with unpredictable outcome

At the end of the nineteenth century several theories about the biological behaviour of bone grafts existed without any consensus Ollier (1867) published the results of his experiments and concluded that the transplanted periosteum and bone remained alive and could become osteogeneic Barth (1908) thought that transplanted bone, periosteum and marrow died and were replaced by surrounding tissues Axhausen's theory (1911) included necrosis of the greatest part of the tranplanted bone with survival of the periosteum and retaining its osteogenic potency in autografts and far less in allografts He stated that bone graft repair was a simultaneous process of resorption and apposition Axhausen's principles were confirmed in later years After publication of his basic research autogenous bone transplantation was successfully performed in patients in the beginning of the 20th century (Albee 1923)

Although already in 1908 Lexer published a series of 23 whole and 11 hemi-joint human allograft procedures around the knee, the clinical use of allografts was limited to fresh allografts because of the unknown biological behaviour of dead bone and the lack of preservation techniques In 1910 Bauer published his animal experiments in which it was shown that allograft bone, preserved by refrigeration, had incorporated Albee (1912) incidentally used frozen bone allografts for clinical purposes A major breakthrough came with the development of preservation techniques, developed by Bush (1947) and Wilson (1951), allowing the storage of allograft bone at -20 degrees Centigrade This made it possible to use allografts clinically on a larger scale At the same time it became clear that allografts were not as successful as autogenous grafts

In the fifties, important animal experiments were done by Chase and Herndon (1954), Burwell and Gowland (1962) and Campbell (1953), to establish the natural history of osseous and chondral allogeneic implants They demonstrated that freezing allograft bone prior to implantation significantly reduced the immune response with concomittant better incorporation In that same period, another important contribution to the understanding of the behaviour of bone grafts was made by Urist (1953), who introduced the theory of osteoinduction He stated that a bone graft functioned as an inductor of ingrowing cells of the host with osteogenic potential In the early 1970s Urist and co-workers (1983) could indeed isolate an organic matrix protein, which was called Bone Morphogenetic Protein (BMP) and proved that this substance induced bone cell differentiation Later on it appeared that BMP was a member of related proteins with different morphogenetic capacities (Urist et al 1983 Aldinger et al 1991)

Once the National Naval Tissue Bank in Bethesda, USA, was established in 1950 as the first bone bank, and several others followed, widespread clinical use of massive allografts became accepted during the sixties, especially to replace traumatically lost or tumourous parts of the skeleton Series of clinical results were published by Parrish (1966) and Ottolenghi (1972) A common feature in these first series was the unpredictable behaviour of the allograft with regard to infection fracture and incorporation

Another important clinical application of bone grafts arose in the seventies, to repair osseous defects in association with primary and revision hip arthroplasty Initial reports by Hastings and Parker (1975) and Harris et al (1977) about acetabular reconstruction with morsellized cancellous and solid cortico-cancellous bone grafts set the stage in this field

2.2 Biology of bone graft incorporation

2.2.1 Comparison of cortical and cancellous grafts

Presently, there is general agreement about the basic events during the incorporation process of non vascularized bone grafts (Goldberg and Stevenson 1987, Friedlander 1987) The biological events are in fact similar for fresh cancellous and cortical grafts, although they differ in rate and extent Sequential events include phases of hemorrhage, necrosis and inflammation revascularization, osteoinduction, osteoconduction and finally remodelling The first phase responds to the surgical trauma associated with implanting the graft Inflammation includes increased vascularity in adjacent tissues dilatation of blood vessels transudation, exudation and oedema The graft is invaded by granulation tissue consisting of polymorphonuclear cells, macrophages foreign body giant cells lymphocytes and mast cells Marrow and osteocytes become necrotic In fresh autologous grafts a few osteoblasts however do survive by diffusion of nutrients and can produce new bone (primary osteogenesis) After subsiding of the inflammatory reaction, fibrous granulation tissue becomes dominant Following this phase a vascularization process develops in which capillaries from the host proliferate and invade the necrotic graft Together with these vessels, perivascular tissue and osteoprogenitor cells, derived from the host, infiltrate the graft This invasion process is called osteoconduction, whereby the graft provides the framework for ingrowth The infiltrating cellular elements have the potential to differentiate into osteoblasts and osteoclasts (secondary osteogenesis) This cell differentiation process, called osteoinduction, is still largely unknown Probably it is modulated largely by low-molecular weight matrix polypeptides of which the glycoprotein bone morphogenic proteins (BMP's) are the most wellknown (Aldinger et al 1991) These BMP's are derived both from the graft and the surface of the host bed (Urist 1953, Urist 1965)

With the presence of osteoblasts and osteoclasts, processes of resorption of dead bone graft and bone apposition are seen simultaneously in the graft Together with the bone apposition, haemopoietic cells appear in the graft and form a viable bone marrow The final phase includes remodelling of the newly formed bone into a mechanically supportive structure, a continuous process under the influence of loading

Until the phase of revascularization there are no main differences in the behaviour of cancellous and cortical grafts During the revascularization phase cortical grafts are more slowly penetrated by capillaries and it takes far more time compared to cancellous grafts before the revascularization is completed (Hammack and Enneking 1960, Goldberg and Lance 1972, Greco et al 1989) The porotic structure of cancellous bone allows a rapid vascular invasion, whereas the dense structure of cortical bone allows only penetration via peripheral osteoclastic resorption

A second difference is the relationship between graft resorption by osteoclasts and new bone apposition by osteoblasts In cancellous bone, graft resorption of preexisting dead trabeculae by osteoclasts is preceded by the apposition of new bone by osteoblasts In cortical grafts, osteoclastic resorption is dominating during the first weeks, principally involving the periphery of the graft After this period bone apposition starts at the graft host interface (creeping substitution)(Enneking et al 1975, Greco et al 1989) In contrast to cancellous grafts, which may be completely replaced by new viable host bone, cortical grafts remain a mixture of viable and necrotic bone (Huo et al 1992)

It is evident that these differences in the behaviour of cancellous and cortical bone grafts must have implications for their mechanical properties In cancellous bone the apposition of new bone on dead trabeculae by osteoblasts, preceeding the resorption of dead bone by osteclasts at the start of the osteoconduction phase, does temporarily increase the width of the trabeculae and increases the mechanical strength of the bone (Goldberg and Stevenson 1987) This phenomenon can be seen on roentgenograms, showing a temporarily denser graft appearance Once bone apposition and resorption are in equilibrium, mechanical strength returns to normal With regard to cortical bone, osteoclastic resorption is dominating for a long period with increased porosity of the graft and up to 40-50% strength reduction compared to normal living cortical bone (Burchardt et al 1975)

As cortical bone grafts remain a mixture of dead and living bone for a long period of time or even permanently, this also influences its mechanical properties Graft necrosis itself, in fact osteocyte necrosis, does not seem to change its mechanical resistance to the single application of load (Enneking et al 1975) However, the repetitive loading of a partial necrotic bone graft can lead to fatique failure as necrotic bone lacks the potential to remodel or repair, in contrast to completely vascularized living bone (Pelker and Friedlander 1987)

As bone graft incorporation is a partnership between host and donor, the condition of the host bone bed with regard to vascularization and metabolism is of eminent importance for successfull incorporation of both cortical and cancellous grafts Rigid immobilization promotes host-graft union and in accordance to Wolff's law, loading of the graft is thought to have a beneficial effect on incorporation although quantitative data are not available (Burchardt 1989)

2.2.2 *Comparison of autografts and allografts*

As is the case for cancellous and cortical grafts there is no difference in the earlier described sequence of biological events during the incorporation process of fresh auto- and allografts, although there are fundamental differences in the rate and extent of distinct phases In many animal experiments during the last decades (Goldberg and Stevenson 1987, Friedlander 1987, Heiple et al 1963, Campbell 1953, Burwell 1969), it appeared that autografts are superior to allografts from a biological point of view, which is expressed in the amount and rate of graft incorporation There is strong evidence that this biological inferiority is caused by immunologic disparity between host and graft (Goldberg et al 1989, Friedlander 1991, Stevenson et al 1991), causing cell-mediated and humoral immune responses (Musculo et al 1976) The immunogenicity of allograft bone is markedly reduced by freezing and reduced even more by freeze-drying Both methods kill all cells, so that primary osteogenesis can not occur However, frozen or freeze-dried allografts show improved incorporation compared to fresh allografts (Brooks et al 1963, Mankin and Friedlander 1989, Friedlander et al 1976, Friedlander 1983)

At the beginning of the revascularization phase the hosts' immune system becomes sensitized to donor antigens from the allograft with, as a consequence, a delay in osteoinduction Proliferating capillaries from the host are occluded by an inflammatory reaction, which reduces or completely prevents revascularization of the graft (Goldberg and Stevenson 1987) Matrix proteins like proteoglycans and, to a lesser extent, collagens can evoke weak immune responses (Friedlander 1991) Probably more important are cell-surface transplantation antigens controlled by the major-histocompatibility complex (Friedlander 1991) In an animal experiment with bone allografts in mice (Horowitz and Friedlander 1991) it appeared that the allograft activated T-cells of the killer/suppressor phenotype and that this response was stimulated by both Class-I and Class-II major histocompatibility-complex antigens Class-I antigens are found on all nucleated cells of the body Class-II antigens are found on B-lymphocytes, activated T-lymphocytes, macrophages and other cells of the macrophage/myeloid lineage Another important finding was that removal of the immunogeneic bone marrow did not alter the immune response.

At least one can conclude at this moment that the rate and extent of allograft incorporation vary considerably and are in fact unpredictable This has consequences for the mechanical properties of the graft and might explain its possible failure in the course of time, as illustrated in a report about retrieved massive allografts (Enneking and Mindell 1991)

Preservation techniques like freezing and freeze-drying have favourable influences on allograft incorporation, although, on the other hand, these techniques influence the physical properties of bone Freezing changes mechanical strength of cortical bone just a little, whereas freeze drying lowers bending strength 55-90% and torsion strength to 39% (Pelker and Friedlander 1987)

2.2.3 Comparison of solid and morsellized grafts

The incorporation process of solid cortico-cancellous grafts is clearly different from morsellized cancellous grafts, as can be concluded from basic studies about the the natural history of bone grafts (Stevenson et al 1991, Goldberg and Stevenson 1987, Friedlander 1987) Morsellized cancellous grafts are incorporated without mechanical weakening, provided that the graft is well contained, has a stable fit and the host-bed is well-vascularized Solid cortico-cancellous grafts remain a mixture of necrotic and viable bone without complete incorporation, with threatening collaps The high incorporation capacity of morsellized cancellous grafts is probably largely due to its greater contact surface with the host bone bed and its open structure

2.3 Etiology of acetabular defects in revision hip arthroplasty

With respect to the acetabular cup of a total hip arthroplasty five main causes for bone-stock loss can be considered

- Congenitally insufficient bone stock (congenital hip dysplasia) (Gordon et al 1985)
- The primary pathologic process (protrusio acetabuli in primary osteoarthritis and rheumatoid arthritis) (McCollum et al 1980)
- Preparation of the acetabular bone bed
  - Reaming and drilling the cement key-holes during the primary hip arthroplasty
  - Removal of cement during revision procedures of failed prostheses
- Periprosthetic osteolysis as a consequence of particle debris and implant (micro)motion in the loosening process
- Infection

The process of periprosthetic osteolysis, in which dissolution of bone takes place, is the most common cause of bone loss around implants (Malcolm 1990) Although it is often associated with loose cemented implants, there are reports describing osteolysis with stable implants, both cemented and cementless, indicating that the origin of osteolysis is not simply the loosening of a cemented implant at the bone-cement interface (Jasty et al 1986, Maloney et al 1990) Several studies (Willert et al 1990, Howie et al 1988, Howie et al 1990) have shown that particle debris of polyethylene, cement and metal, combined or alone, can produce bone resorption at the bone implant interface in the presence of a stable implant These particles are ingested by macrophages and giant cells, which become activated and release several chemical mediators, like prostaglandins and interleukins, which activate osteoclasts and induce a bone resorption process Also a resorption mechanism was described in which synovial like cells within the interfacial membrane around implants produce osteolytic enzymes like collagenase (Goldring et al 1983) It is still unclear what influence the number and size of the different particles have on the intensity of the biological responses

Prosthesis infection is also accompanied by osteolysis and can result in significant bone resorption

2.4 Classification of acetabular defects

In order to make a preoperative plan, to discuss specific types of problems or to compare different reconstruction techniques, it is important to define and classify acetabular defects The American Academy of Orthopaedic Surgeons (AAOS), Committee on the Hip, devised a usefull classification system for acetabular deficiencies (D'Antonio et al 1989) The system defines two basic categories segmental and cavitary defects (table 2 1) A segmental defect is any complete loss of bone in the supporting hemisphere of the acetabulum, including the medial wall Cavitary defects represent a volumetric loss in bony substance of the acetabular cavity, including the medial wall A medial cavitary defect, for example, implies ex-

Table 2.1 *Classification of acetabular deficiencies (AAOS)*

Type I	
	Segmental deficiencies
	Peripheral (superior, anterior, posterior)
	– Central (medial wall absent)
Type II	
	Cavitary deficiencies
	– Peripheral (superior, anterior, posterior)
	Central (medial wall intact)
Type III	
	Combined segmental/cavitary deficiencies
Type IV	
	Pelvic discontinuity
Type V	
	Arthrodesis

Figure 2.1. *Medial cavitary defect. Osteoarthritis of the hip with acetabular protrusion*

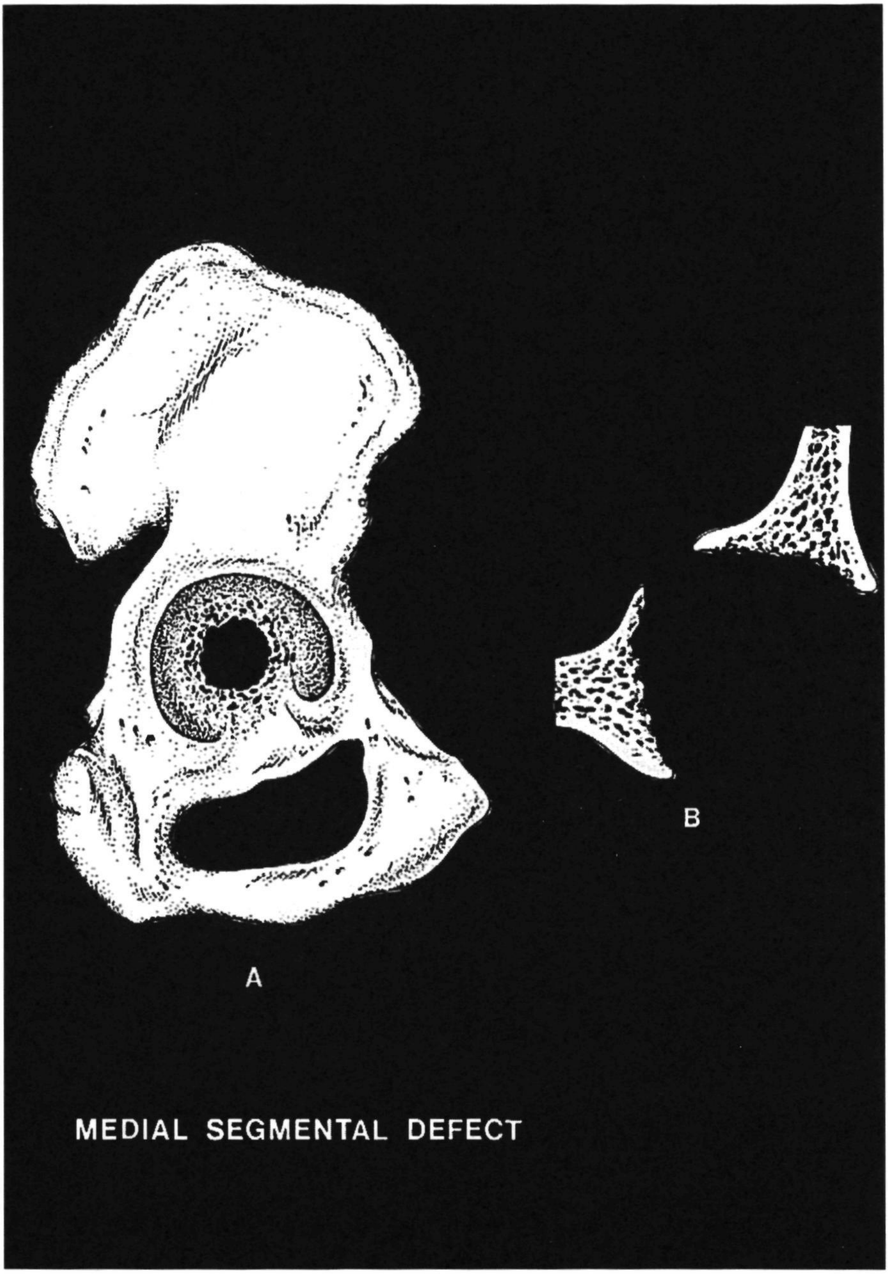

Figure 2.2. *Drawing of a segmental defect in the medial wall*
A. Lateral-medial view in the acetabulum
B. Section of the acetabulum in the frontal plane

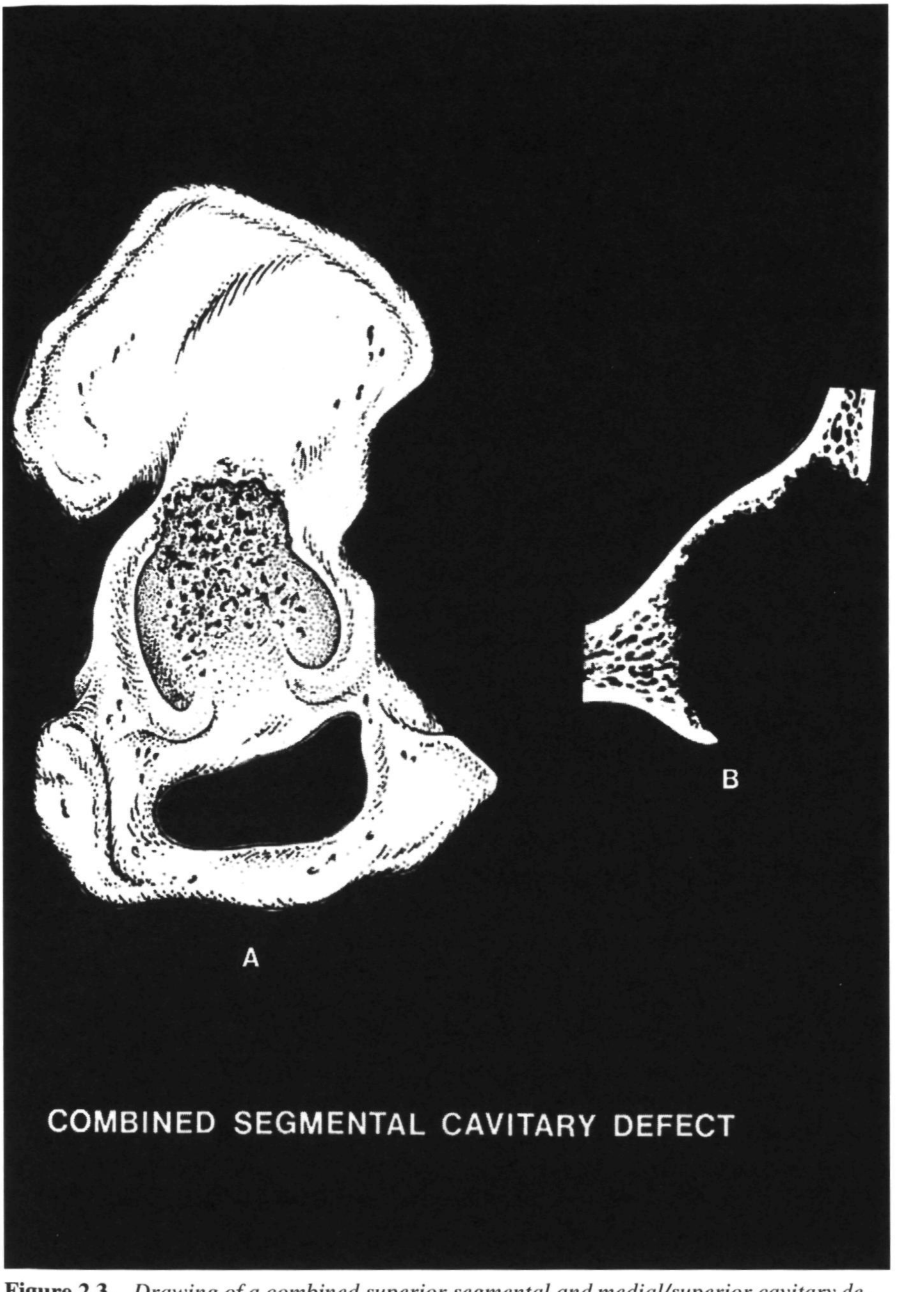

Figure 2.3. *Drawing of a combined superior segmental and medial/superior cavitary defect. A. Lateral-medial view in the acetabulum. B. Section of the acetabulum in the frontal plane*

cavation of the medial wall without perforation (fig 2 1) In contrast, a medial segmental defect represents a perforation or complete absence of the medial wall (fig 2 2) In practice, several different combinations of deficiencies exist (fig 2 3) Pelvic discontinuity is a defect across the anterior and posterior columns with total separation of the superior part from the inferior part of the acetabulum

2.5 General aspects of acetabular component revision

2 5 1 Management of peripheral segmental acetabular deficiencies

The most frequently encountered peripheral segmental defects are the superior rim defects (fig 2 4) They occur isolated or in combination with other defects In revision surgery these defects are most commonly encountered after initial total hip replacement in a congenital dysplastic hip or in a subluxated hip due to osteoarthritis or rheumatoid arthritis In these instances it is often seen that the acetabular component and cement are not completely covered with bone and a so-called "socket breakout" has occured (Harris 1982) Combination of superior segmental defects with other defects (figs 2 3 and 2 5) are mostly secondary to failed previous surgery Posterior segmental defects are seldom seen in isolation They are mostly encounterd after a failed previous hip replacement in which there is often a combination with superior segmental and other defects Chandler and Penenberg (1989) reported an incidence of 61% periferal segmental defects, isolated or combined with other defects, in their series of 76 acetabular grafts

In the literature most authors agree that solid block graft reconstruction is essential for prosthetic support with respect to segmental defects (fig 2 6) (Schuller et al 1993) Gerber and Harris (1986) reported a 20% failure rate in a series of 47 primary hip replacements with peripheral segmental defects, using femoral head autografts, after an average follow-up of 7 years They stressed the importance of reconstructing accompanying posterior segmental defects more graft resorption was seen in cases with a lack of posterior osseous support Good clinical results with femoral head allografts for reconstruction of peripheral segmental defects were reported by Trancik et al (1986) in a series of cemented revision hip replacements with an average follow up of 3 5 years Conventional radiographs and single photon emission computed tomography showed succesfull incorporation in 20 of 21 solid allografts

Oakeshott et al (1987) reported good clinical and radiological results of cemented and cementless revision hip arthroplasty with femoral head allografts fixed with bolts to the ilium for superior segmental defects In a series of 18 allografts with autogeneic cancellous graft supplementation at the graft-host interface, 12 allografts showed complete union and 4 grafts partial union Component migration was only seen in 2 cases with a bipolar prosthesis Average follow-up was 20 months In most allografts the unloaded part resorbed, without affecting the supporting part of the graft

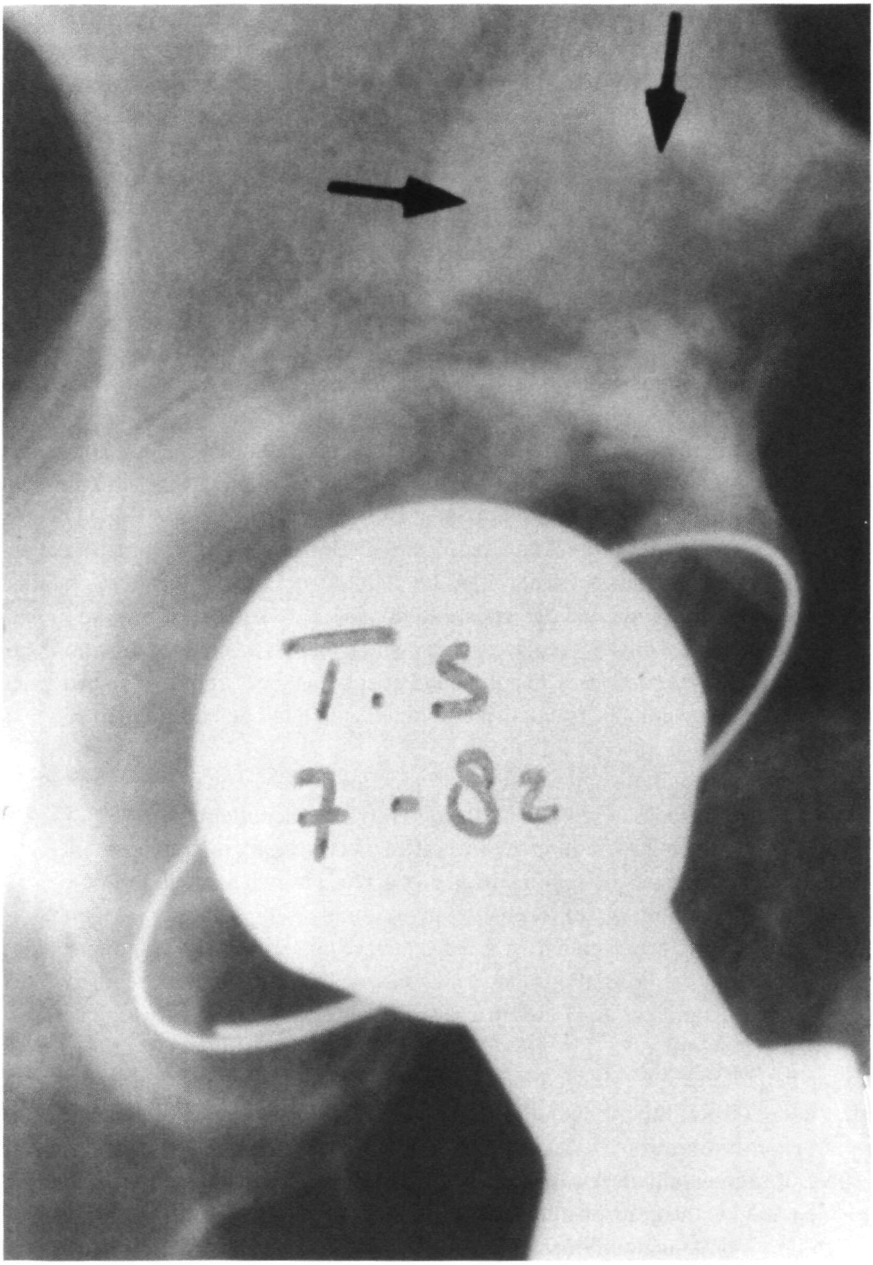

Figure 2.4. *Superior segmental defect in the presence of a cemented cup*

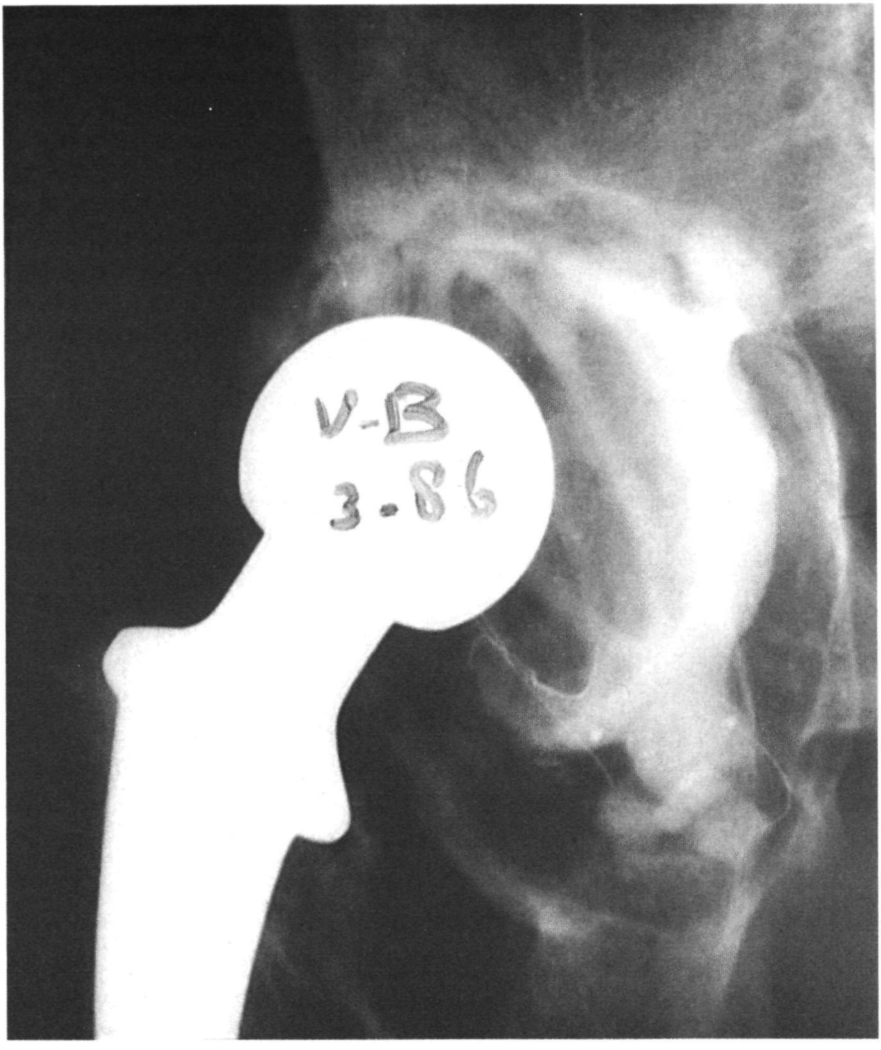

Figure 2.5. *Superior segmental, medial/superior cavitary type defect in the presence of a migrated cemented cup*

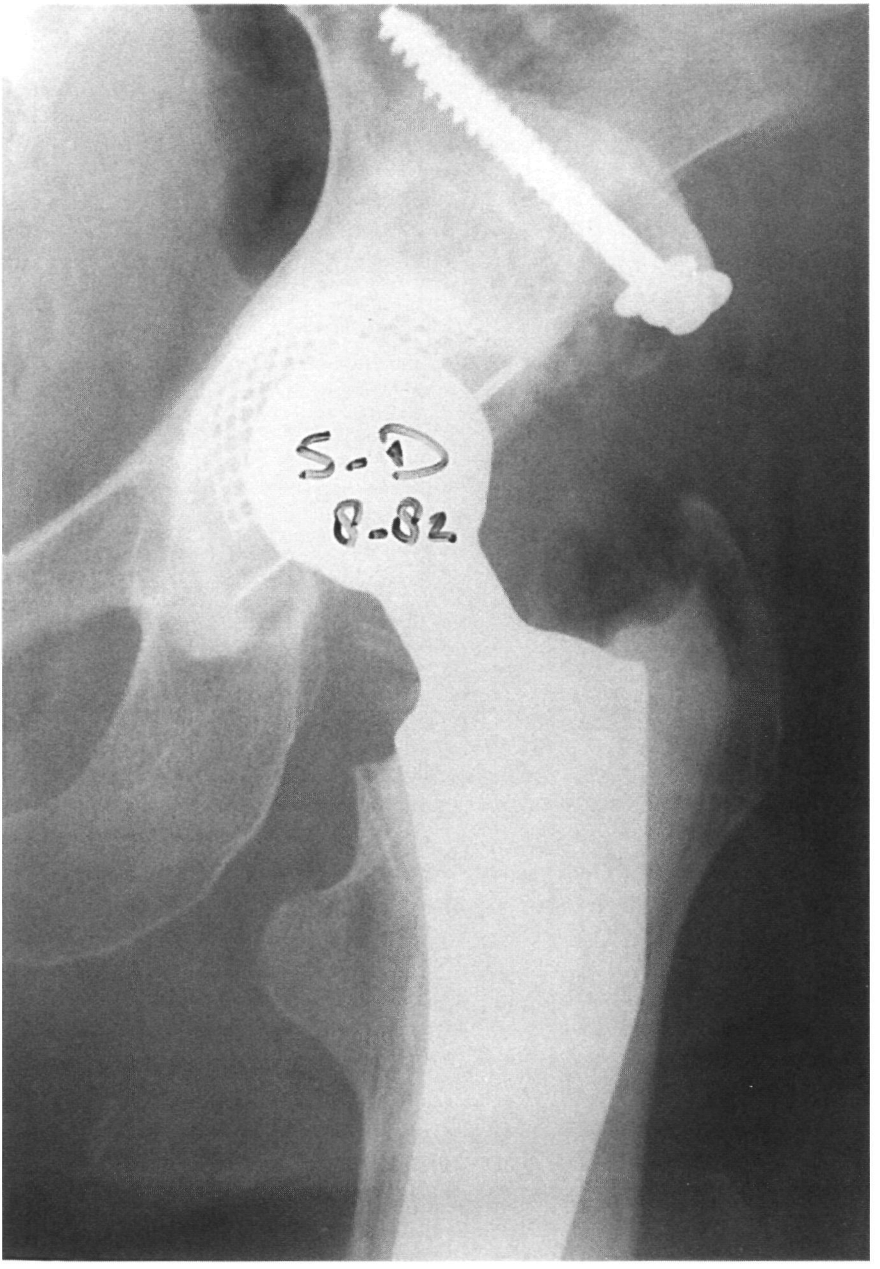

Figure 2.6. *Superior segmental defect reconstruction with a solid cortico-cancellous block-graft fixed with screws. The accompanying superior cavitary type defect is reconstructed with chips*

Jasty and Harris (1990), reporting their results of 38 acetabular reconstructions with solid allografts with a mean follow-up of 5 9 years, concluded that structural allografts provided only a short-term solution They found a failure rate of 32%, due to resorption of the graft and fracture of the cement layer at the allograft-host junction, between 4 and 9 years after surgery The slow and incomplete revascularization of structural allografts, which takes up several years, might have been responsible for the late collapse Young et al (1991) found a comparable failure rate of 17 5% failures and 12 5% impending failures with an average follow-up of 4 years in a series of 40 reconstructions, including 11 femoral head allografts for superior segmental defects In both studies of Jasty and Young, acetabular loosening was more common when graft coverage increased Young et al also found that all failures were related to technical errors in fit and fixation of the graft An important technical point was stressed by Chandler et al (1990) in a six year follow-up study of solid acetabular bone grafts They found that in most failures with graft collapse, the graft trabeculae and fixating screws were oriented transverse to the weight-bearing axis They advise to orient screws and trabeculae in the direction of the weight bearing axis

Emerson et al (1989) comparing the behaviour of peripheral structural allografts with bipolar cups, screw-in cups and press-fit cups, found reliable graft healing and good clinical scores only with the press-fit design Less graft resorption and failure was found when grafts were fixated with buttress plating combined with interfragmentary screw fixation They postulated that the cause of failure is the lack of graft support rather than cup support After analyzing their results of 8 reconstructed superior segmental defects with massive femoral head allografts, Wilson et al (1989) concluded that grafts thicker than 15 millimeters in such defects are incapable of complete repair

A different technique was used by Olivier and Sanouiller (1991) They prefer the use of morsellized cancellous chips based on the fact that their incorporation is more consistent and rapid compared to solid cortico-cancellous grafts They could reconstruct most periferal segmental defects with impacted cancellous chips in combination with an Eichler support ring In most cases, a lasting stable situation was achieved with full radiographic graft incorporation

2.5.2 Management of medial segmental acetabular deficiencies

Isolated medial segmental defects in revision hip arthroplasty are rare (fig 2 2) Most of these defects occur in combination with other defects Conditions that produce these types of defects are overreaming of the acetabulum in patients with congenital hip dislocation, traumatic fracture dislocation, the insertion of cementless threaded cups and the migration of loose cemented cups, producing bone resorption and fatique fractures of the medial wall

In the seventies Jasty and Harris (1988) used a technique in which a Vitallium mesh covered the defect and reinforced the cement In a study with an average follow-up of 6 8 years, loosening was found to have occured in 14% of hips with a medial segmental defect measuring less than 1 cm and 75% of hips with larger defects Crowninshield et al (1983) concluded after Finite Element analysis, that a mesh covering a medial segmental defect has no beneficial effect on the reduction of medial acetabular stresses.

Lord (1988) reported unsatisfactory results using a threaded metal cup without grafting the medial defect, probably because of bad fixation on the bone bed of poor quality. McCollum et al. (1980) were the first who reported about the use of bone grafts in medial segmental defects. Their technique was to cover the defect with a wafer of autologous or homologous solid cortico-cancellous bone 1 cm in thickness, with some overlap (fig. 2.7). A fine Vitallium mesh was placed over the graft and a cup was cemented in position. When the medial wall was completely absent, an Eichler protrusio ring was used to stabilize the prosthesis, while the graft was healing. In their follow-up study after 4.7 years all 39 grafts appeared to be united radiographically. After average 12.8 years follow-up 20% had definitely loosened radiographically (Gates et al. 1990). Cameron (1985) described some methods for acetabular floor defects. In segmental defects less than 1 centimeter in diameter, cancellous bone is pushed through the hole, forming a collar stud of bone and the hole is occluded by a Charnley cement restrictor. Defects between 1 and 3 centimeter were repaired by a block of cortico-cancellous bone from the iliac wing, slightly greater than the size of the defect, which is pushed through the defect in the pelvis. The intra-abdominal pressure and periosteum hold the graft in place. Major isolated floor defects with intact columns were handled using a bipolar prosthesis, with the biggest head possible, to transfer load to the side walls of the acetabulum rather than the floor. Morsellized bone grafts were laid in the defect and the patient was kept non-weightbearing until radiographic signs of graft healing were seen. Series reported by Wilson et al. (1989) and Brien et al. (1990), dealing with medial segmental defects treated by morsellized grafts with bipolar prosthesis, showed high rates of migration of the socket and resorption of the graft. Olivier and Sanouiller (1991), Samuelson and Freeman (1990), Fuchs et al. (1988) used support rings in combination with morsellized cancellous grafts, like the original technique of McCollum and Nunley (1981). Their role is to avoid medial migration during the graft incorporation process and to distribute the load around the acetabulum. For large medial segmental segments after penetration of a loose cup and cement into the pelvis Harris (1977) proposed a technique of intrapelvic grafting, in which a full thickness piece of iliac wing is bolted to the innominate bone using an intrapelvic approach. Chandler and Penenberg (1989) closed the defect with strips of cortico-cancellous bone and used a porous coated acetabular component large enough to span the defect. Intact anterior and posterior columns were necessary to achieve primary stability. This technique was also advocated by Clarke et al. (1988), who reported good radiographic incorporation of morsellized grafts in porous coated cups at an average follow-up of 2.6 years. Solonen et al. (1988) described a two-stage procedure for revising hips with large segmental defects in 3 cases with an autologous vascularized pedicular iliac bone graft.

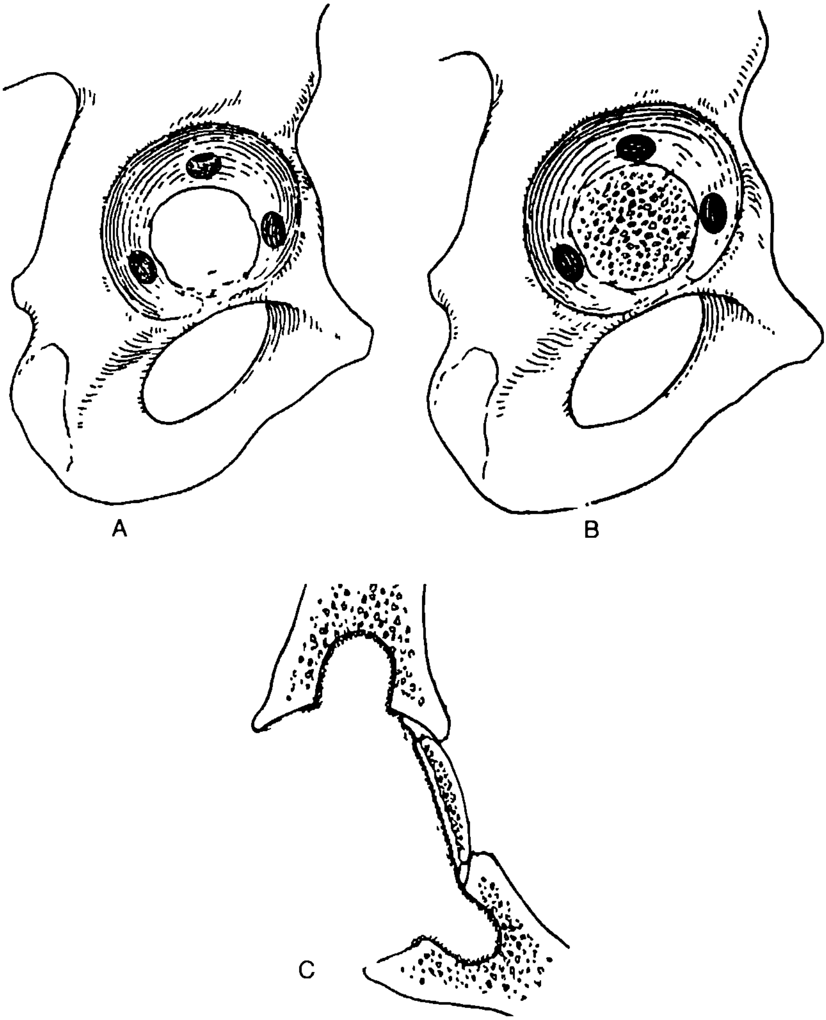

Figure 2.7. *Technique according to McCollum et al (1980)*
A Lateral-medial view of acetabulum with a medial segmental defect
B Lateral-medial view of acetabulum after closure of defect with a cortico-cancellous shell
C Section of acetabulum in frontal plane after closure of defect with a cortico-cancellous shell

2.5.3 Management of cavitary acetabular deficiencies

Cavitary defects are frequently encountered in revision hip surgery Small defects are commonly caused by lysis about a cement keying hole Larger defects usually result from migration of a loose acetabular component with associated bone lysis As acetabular protrusion is frequently encountered in primary total hip arthroplasty (fig 2 1), it is not surprising that the first reports in the literature were dealing with experiences in treating this type of cavitary defect in primary hip situations

Sotelo-Garza and Charnley (1978) reported good results with cement alone to treat acetabular protrusion In contrast with these findings, Salvati et al (1975), Ranawat et al (1980) and Azuma (1985) found high failure rates with cement alone and they advised the use of bone grafts

Hastings and Parker (1975) were the first to report about five cases of protrusio acetabuli in rheumatoid arthritis in which the medial wall was built up with morsellized autogenous cancellous grafts from the femoral head combined with cemented total hip replacement McCollum et al (1980), Heywood (1980) and Augereau and Postel (1980) used a structural layer of cortico-cancellous bone to reinforce the medial wall and covered it with a metal mesh A 12 8 years study of the patient group of McCollum et al (1980) showed 20% definite loosening radiographically (Gates et al 1990) Good results were reported by Hirst et al (1987) in a series of 61 primary cemented arthroplasties using thin wafers of cancellous autograft bone with a follow-up of 4 3 years

Chandler and Peneberg (1989) preferred the use of morsellized grafts with non-cemented acetabular devices In very large defects solid bulk grafts were used without cement They abandoned the use of support rings in cavitary defects, because of medial acetabular stress shielding Bayley et al (1987) analyzed 93 patients treated for medial cavitary defects with cement alone, cement with metal reinforcement rings or morsellized bone graft with cement, with a minimum follow-up of 3 years and found a high failure rate in the cement alone group and equally good results in the bone graft and metal-reinforcement group

Mendes et al (1984) and Slooff et al (1984) published the first series of patients with medial cavitary defect reconstruction, using only impacted morsellized auto- or allografts in both cemented primary and revision hip arthroplasties They used impacted morsellized grafts because of the stronger osteogeneic potential and faster incorporation without temporary mechanical weakening of the graft, as is the case in structural grafts during the process of creeping substitution At an average follow-up of 4 and 2 years respectively, in both patient groups of 8 and 43 patients respectively, full graft incorporation was assessed radiographically without signs of cup loosening or graft resorption No differences were found between auto- and allografts. Marti and Besselaar (1983) used a comparable technique in which a cortico-cancellous shell was laid under the morsellized grafts at the bottom of the intact cavity

Olivier and Sanouiller (1991) stressed the biological advantages of morsellized cancellous allografts compared to solid bulk grafts in cavitary defects They allow better bone-cement interlock, their incorporation is more complete and rapid, and their malleable nature allows better adaptation to a cavitary defect with a greater contact surface In their series of cemented revision arthroplasties with cavitary defects they reported complete radiographic graft incorporation at the same rate in auto and allografts without resorption Samuelson et al (1990) also favoured the use of morsellized cancellous allografts, although they abandoned the use of cement, because the cement diminishes the amount of bone graft which can be used, possible poor initial stability of a cemented implant in an unfixed layer of bone graft and suspected damaging effect of the cement to the graft incorporation process

Wilson et al (1989) and Oakeshott et al (1987), comparing solid and morsellized cancellous allografts in medial cavitary defects in revision bipolar hip arthroplasty, saw a slightly faster radiographic incorporation of the morsellized grafts, but less implant migration and graft resorption in the solid group

2.5.4 Management of pelvic discontinuity

This type of extensive bone loss, involving column defects often combined with medial segmental defects, is not a frequently occuring problem Therefore, reports in the literature dealing with this type of defect are sparse However, there is general consensus that the only treatment option in these cases is the use of massive structural allografts Mostly several femoral heads or complete acetabular allografts are required (Chandler and Penenberg 1989) Oakeshott et al (1987) reported about twenty reconstructions of pelvic discontinuity with eleven segmental femoral head allografts and nine total acetabular allografts Fourteen cementless sockets were used including seven bipolar prostheses and six sockets were cemented There were three non-unions, one related to infection Some degree of graft resorption was only seen in the group of bipolar prostheses The union rate was equivalent in both types of graft Two sockets became loose, one related to infection

2.5.5 Summary

In the last decades of the 19th century basic research was started to investigate the sequence of events in the incorporation of bone auto- and allografts In the 1950s the natural history of bone graft incorporation was established definitely Cancellous bone grafts appear to incorporate more rapidly and completely, compared to cortical grafts, without temporarily mechanical weakening, as is the case in cortical bone The sequence of events in auto- and allografts is the same, although they differ in rate and extent, predominantly caused by immune responses to allograft bone Morsellized bone grafts have a higher capacity to incorporate, compared to solid grafts In the 1970s first reports appear about the use of bone grafts combined with hip implants, especially at the acetabular side Peripheral segmental acetabular defects were preferably reconstructed with solid bone grafts fixed to the iliac wall, although late collapse of these grafts is reported by some authors Medial segmental defects are mostly reconstructed with slices of cortico-cancellous bone, combined with metallic reinforcement devices Contained cavitary defects are treated in majority of cases with slices of cancellous bone, whereas some authors prefere the use of impacted morsellized bone grafts No unanimity exists regarding the use of cemented or cementless implants Pelvic discontinuity, involving two-column defects, requires the use of total acetabular allografts

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CHAPTER 3

Acetabular reconstruction with impacted morsellized cancellous allograft in cemented hip arthroplasty: a histological study in the goat

3.1 Introduction

Acetabular bone stock loss associated with a loosened socket is a common feature in revision hip surgery (D'Antonio et al 1989, Chandler and Penenberg 1989) Also in up to 15% of primary hip replacements, insufficient acetabular bone stock is encountered due to protrusio acetabuli or dysplasia (Edelstein and Murphy 1983 McCollum et al 1980) Controversy still exists about the treatment of choice for these bone stock deficiencies extra quantities of cement (Sotelo-Garza and Charnley 1978), metal devices (Eichler 1973), custom made implants (Scales and Wright 1983) and bone grafts (D'Antonio et al 1989) have been proposed However, with regard to acetabular bone stock deficiency in primary total hip replacement, there has been a strong tendency in the literature over the past decades for authors to describe a biological reconstruction with bone grafts as the method of choice (Chandler and Penenberg 1989)

It has become commonly accepted that autografts are superior to allografts with respect to their consolidation and incorporation capacity (Heiple et al 1963) However, in many cases the defects are too large for reconstruction with the patient's own bone stock Therefore, a growing number of bone banks has been established and the use of allograft bone has been introduced in orthopaedic practice At our institute, we have been using a standardized bone grafting technique with impacted morsellized cancellous allografts from the bone bank combined with a cemented acetabular cup to reconstruct acetabular defects in revision hip arthroplasty since 1979 (Slooff et al 1984) In the literature, only the clinical results of this technique have been described (Hirst et al 1987, McCollum et al 1980, Olivier and Sanouiller 1991, Slooff et al 1984, Slooff et al 1993) No data are available about the biological behaviour of acetabular bone grafts in total hip arthroplasty

The purpose of this histological study was to investigate, in an animal model, the speed of consolidation with the host bone bed, to clarify the mechanism of incorporation of the graft into a new bony structure and to study events at the graft-cement interface during revitalization Special attention was paid to the possible relationships between the incorporation process of the graft and early and late loosening of the acetabular cup

3.2 Material and methods

The study was performed on 23 skeletally mature Dutch milk goats (Capra Hircus Sana) of about 2 years old and weighing between 48 8 and 79 3 kg (average 60 3 kg) (fig 3 1) The

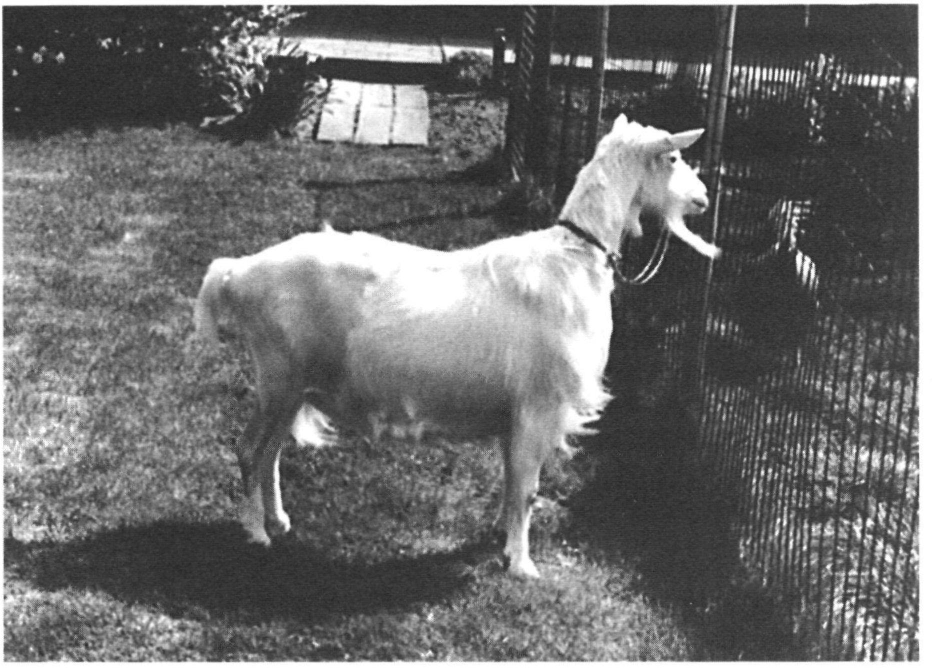

Figure 3.1. *One of the goats used in the animal experiment (Capra Hircus Sana)*

allografts were harvested, under sterile conditions, from another goats' sternum, packed as small chips of 1/4-1/2 cm diameter in sterile bags, after cultures had been taken and stored at -70 degrees Celsius. Just before use they were thawed in physiological saline. Anaesthesia was induced by intravenous Nembutal (30mg/kg) and atropine 0.5 mg and maintained via endotracheal intubation with a mixture of nitrous oxide, oxygen and halothane in a closed circuit. After 500 mg ampicillin iv. had been administered as antibiotic prophylaxis and routine aseptic measures had been taken, the right hip was exposed via an antero-lateral approach. Total capsulectomy and femoral neck osteotomy were performed. The acetabular cavity was cleared of soft tissues and reamed to a diameter of 29 mm, taking care not to penetrate the medial wall (fig. 3.2a). With a speed burr, a standard defect was made in the dorso-cranial part of the acetabulum, including the peripheral rim, with a maximal depth of 1.5 centimeters (fig. 3.2b). Many small burr holes (2 mm) were made in the cortical bone of the ilium and acetabular cavity to stimulate vascularization of the recipient bone bed (fig. 3.2c). After cleaning and drying, the defect and the acetabular cavity were filled with allograft chips (fig. 3.2d) and impacted with a 25 mm diameter socket trial prosthesis in such a way, that the socket was localized in the anatomical position, thus restoring the original centre of rotation (fig. 3.2e). The acetabular cavity, apart from the caudal and ventral walls, was completely covered with a layer of allograft chips and a 22 mm polyethylene cup

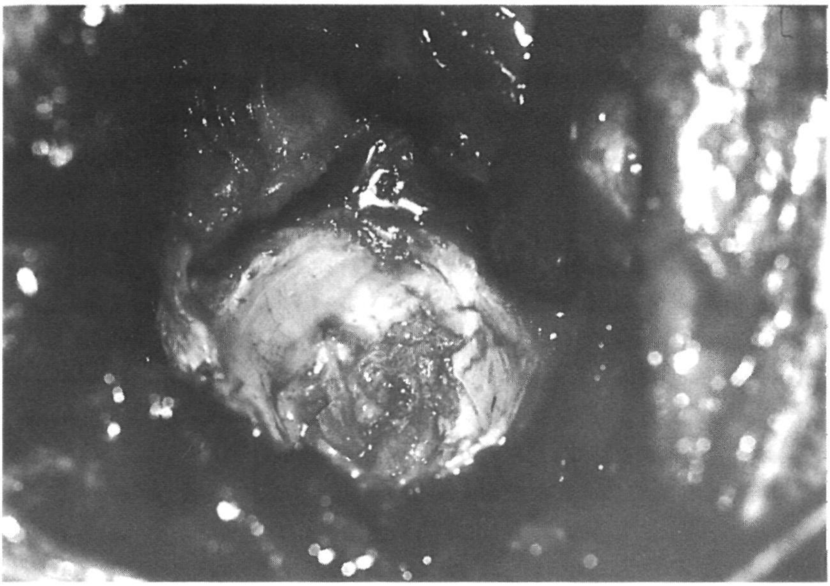

Figure 3.2a. *Acetabulum after resection of the femoral head showing intact articular cartilage and the cut teres capitis ligament.*

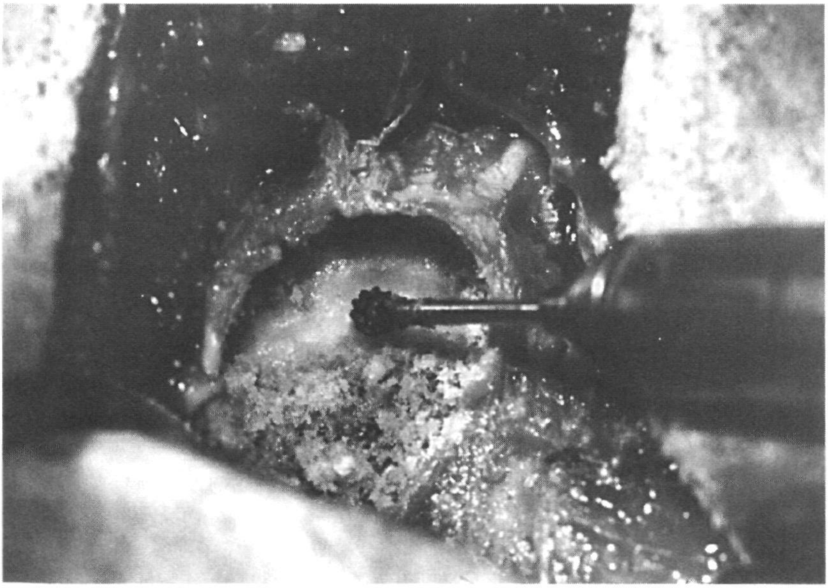

Figure 3.2b. *After the acetabulum was reamed to 29 mm diameter a defect in the cranial-superior segment was created by a speed burr.*

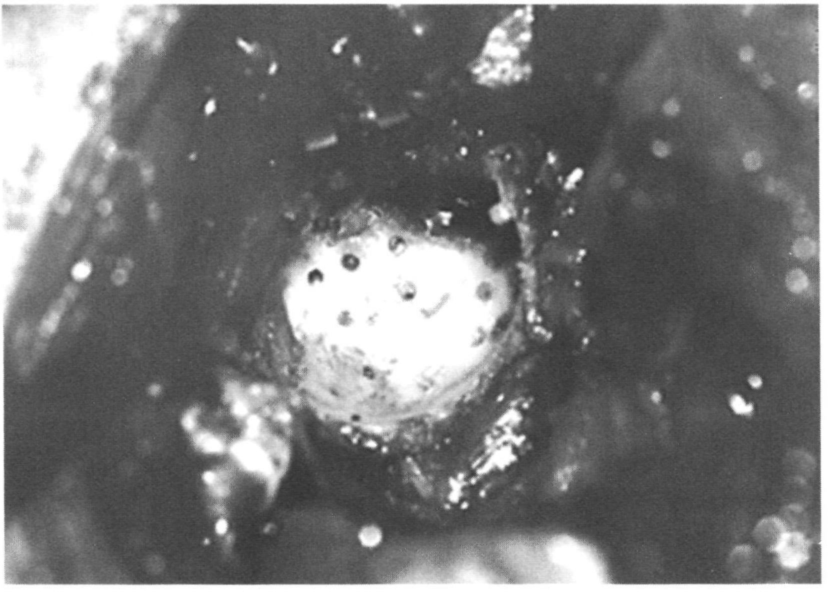

Figure 3.2c. *Multiple drill holes (2 mm) in the recipient bone bed.*

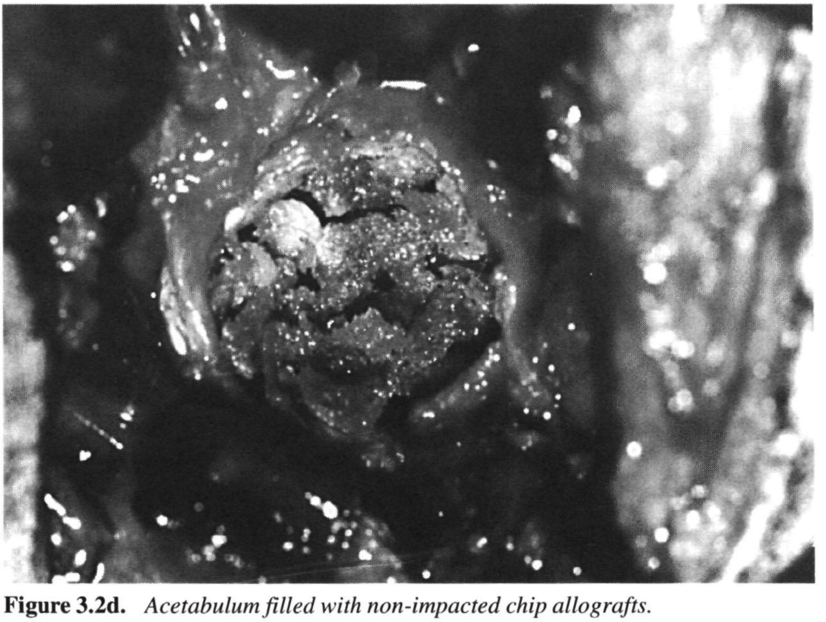

Figure 3.2d. *Acetabulum filled with non-impacted chip allografts.*

Figure 3.2e. *After impaction of the chips. Largest parts of the acetabulum covered with a layer of chips.*

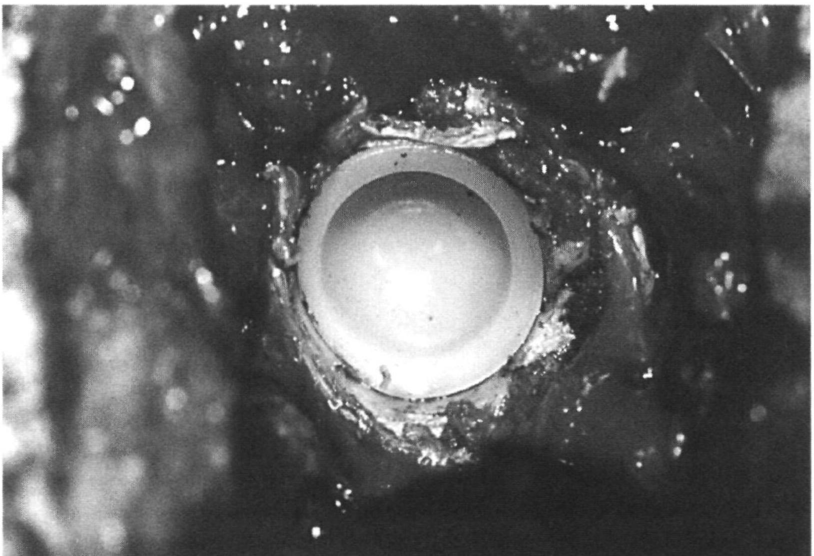

Figure 3.2f. *Cup with an outer diameter of 22 mm cemented in the reconstructed acetabulum.*

Figure 3.2g. *Femoral component cemented in the femur.*

(Mathys, Bettlach, Switzerland) was inserted and cemented in place (fig. 3.2f). The femoral canal was then reamed, a plastic plug (Allopro) was inserted and the femoral component (Mathys, Bettlach, Switzerland) was cemented in place (fig. 3.2g). The femoral component was made out of cobalt-chromium alloy and had a 16 mm head. CMW low-viscosity cement was used for fixation. The hip was reduced and the wound closed in layers. Immediately after the operation, standard antero-posterior pelvic radiographs were taken (fig. 4.2a). The goats were immobilized for 2 days in a special hammock in which both hindlegs were not loaded. Free weight-bearing and exercise were allowed in the subsequent period. The weight-bearing patterns were assessed at 3, 6, 12, 24 and 48 weeks, using the grading scale according to Ypma (1981). Calcein green was administered (25 mg/kg) subcutaneously on days 9, 8, 2 and 1 before the animals were killed and evaluated. Radiographs were taken only when dislocation, fracture or premature loosening was suspected. Three animals were killed with an overdose of pentobarbitone immediately after surgery; 4 goats were killed at 3, 6, 12, 24 and 48 weeks after surgery. Antero-posterior pelvic radiographs were then taken. A selected group of animals, indicated with the letter H after their number (table 3.1), were perfused with barium sulphate for microangiography. All the other animals were routinely perfused with 4% 0.1M phosphate-buffered (pH 7.4) paraformaldehyde. Block resection of the acetabulum was performed by osteotomy of the ilium, upper arch of the pubic bone and ischial bone. The components were inspected, tested manually for stability and scored on a grading scale (table 3.1). No further analyses were performed in the case of gross purulence

Table 3.1. *Clinical score*

Follow-up (weeks)	Goat number	Weightbearing 3	6	12	24	48 (weeks)	Fixation Stem	Cup	Complications
0	56LB						3	3	
0	57LB						3	3	
0	59LB						3	3	
3	69B	4					3	3	
3	70B	3					3	3	
3	75B	3					3	3	P
3	87H	0					3	3	D
6	71H	3	4				3	3	I
6	73H	3	4				3	3	P
6	80H	2	3				3	3	D
6	83H	3	3				3	3	F
12	81B	3	4	4			3	3	
12	82B	4	4	4			3	3	
12	84H	4	4	4			3	3	
12	88B	4	2	1			1	1	I
24	61H	2	3	2	2		1	3	
24	64H	3	2	1	1		0	1	
24	66H	3	4	4	4		3	3	
24	72H	3	4	4	4		3	3	
48	56RB	3	4	4	4	1	0	3	
48	57RB	3	4	2	2	2	0	0	
48	59RB	3	4	3	2	1	0	0	
48	62H	3	3	4	4	4	0	2	

Weight bearing (according to Ypma (1981))
0 = not used at all
1 = supported incidentally
2 = loaded in a standing position and incidentally while walking
3 = loaded in a standing position and while walking but with a limp
4 = normal walking and standing pattern

Fixation at evaluation (according to Ypma (1981))
0 = completely loose and extractable without any force
1 = slightly movable
2 = stable but extractable by hand
3 = fully stable

Table 3.1. *Clinical score (continued)*

Complications
P = peroperative medial wall perforation
D = dislocation
I = infection proven by positive culture
F = femoral fracture

at harvest or full luxation of the components. The left femur and acetabulum of each goat served as a control. After fixation, the acetabuli were embedded in plaster of Paris and sawn in the medial-lateral plane into slices of 2-3 mm thick with a water-cooled saw (fig. 3.3a and 3.3b). The slices were then X-rayed. For routine histology, the slices were decalcified in 25% EDTA under X-ray control, embedded in polymethyl-methacrylate

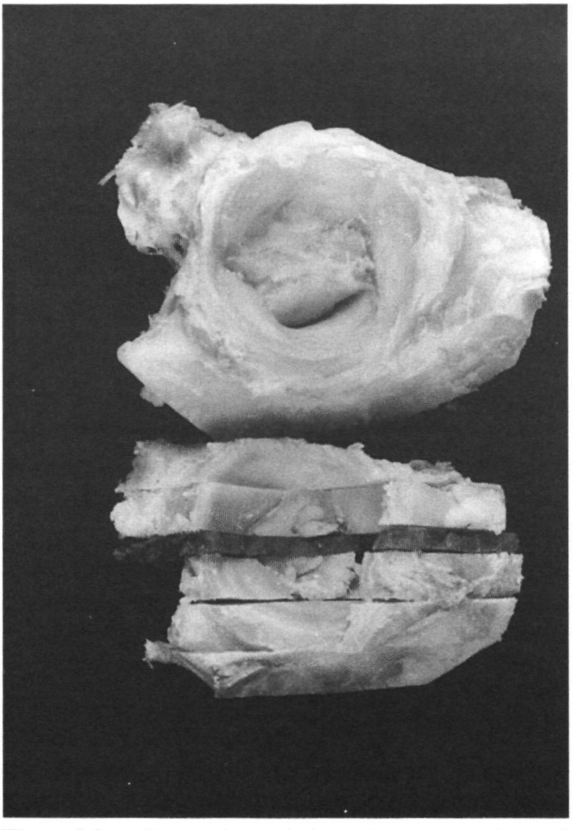

Figure 3.3a. *Resected acetabulum of not-operated contalateral hip after sectioning in the anatomical medial-lateral plane.*

(PMMA), thin sectioned (7 µm) and stained with haematoxylin-eosin (HE). For fluorescence microscopy, unstained, non-decalcified 3 mm thick slices were embedded in PMMA and sectioned (20 µm) using a Leitz 1600 rotating water-cooled diamond saw. For microangiography the slices were decalcified in formic acid and X-rayed.

3.3 Results

3.3.1 Clinical performance and complications of the operation

All the animals were ambulated and allowed full weight bearing after two days in a hammock. The average clinical scores were 3.13 (±0.50, n=16) after 3 weeks, 3.62 (±0.65, n=12) afer 6 weeks, 3.27 (± 1.10, n=11) after 12 weeks, 2.88. (± 1.25, n=8) after 24 weeks and 2.00. (±1.41, n=4) after 48 weeks (infections, dislocations and fractures excluded). The clinical

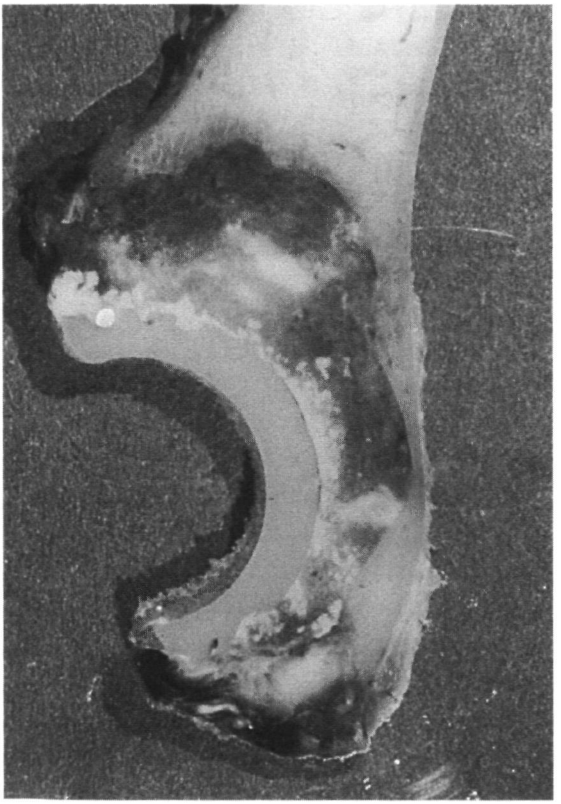

Figure 3.3b. *One of the slices of the sectioned acetabulum 3 weeks postoperatively. Boundary of graft with host bone can be clearly distinguished.*

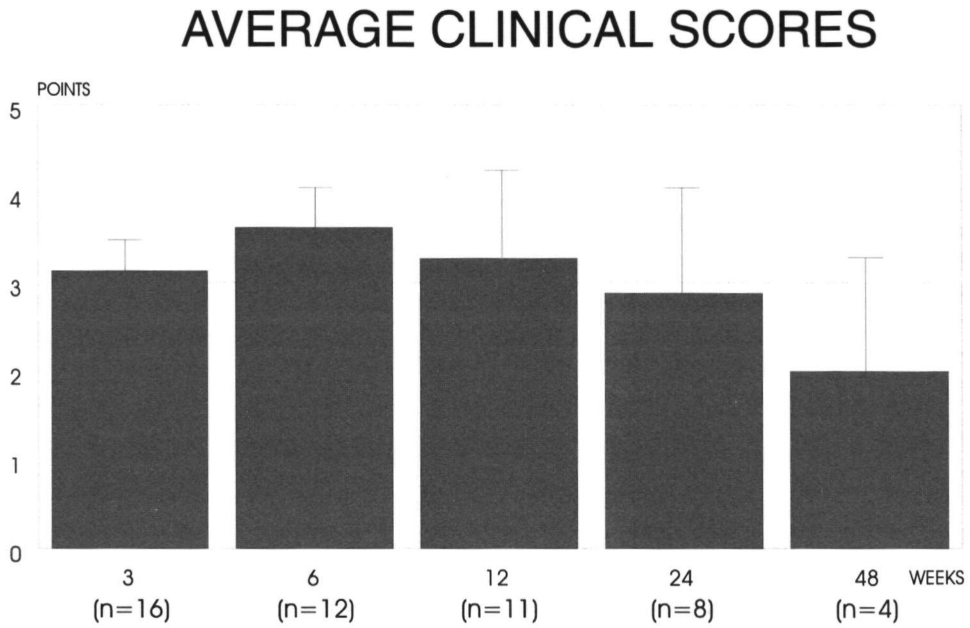

Figure 3.4a. *Diagram representing average clinical scores according to Ypma (1981).*

scores are summarized in table 3.1 and figure 3.4a. From these scores it could be deduced that the initial clinical score was good, but that after 6 weeks, the weight bearing pattern showed the tendency to deteriorate. Although the scores were lower in the longer follow-up periods, they were found to vary widely from animal to animal. Cup fixation at sacrifice is represented in figure 3.4b.

Goat 64H (killed after 24 weeks) and goats 57RB and 59RB (killed after 48 weeks) showed complete loosening of the cup without any clear signs of infection. One goat (62H) (killed after 48 weeks) showed early signs of cup loosening. In two specimens (71H and 88B) positive cultures of Staph. epidermidis were found. Histological evaluation revealed massive infiltration of polymorphonuclear lymphocytes, macrophages and foreign body giant cells throughout the graft, which extended into the host bone bed. No signs of union were seen. Osteoclastic resorption of the graft and living host bone had resulted in the formation of a thick fibrous tissue interface with large fibrin deposits. Also large periosteal reactions with callous formation were found in these specimens. Two hips became dislocated (87H, 80H). Infections were excluded from the analyses. One goat (83H) had a femoral fracture at the tip of the stem at 6 weeks, just before it was scheduled for evaluation.

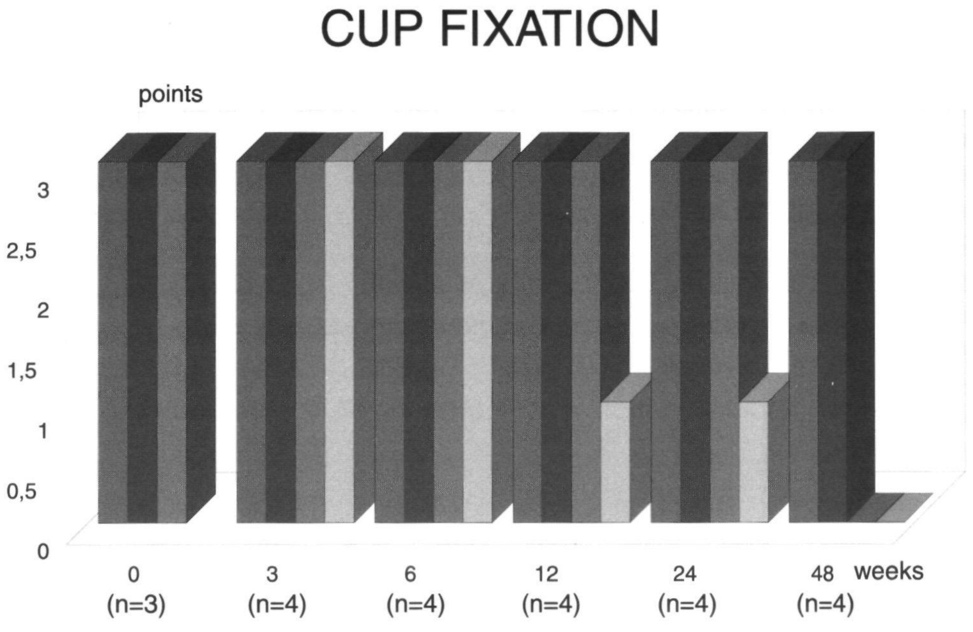

Figure 3.4b. *Diagram representing cup fixation at sacrifice according to Ypma (1981).*

3.3.2 Histological analysis

3.3.2.1 0 weeks (goats 56LB, 57LB, 59LB)

On the X-rays, the impacted graft could be recognized easily in the defect (fig. 3.5b). At the host-graft interface, a thin sclerotic layer was present (fig. 3.5b), which consisted of small bone fragments that had been squeezed between the trabeculae of the host bone bed during the preparation of the defect. The effect of impaction was clearly visible. Large areas of the graft did not show a typical trabecular pattern (Fig. 3.5c). Much of the intramedullary fat in the pieces of graft had been squeezed out during the process of impaction. Locally, the inter-trabecular spaces were filled with fibrin clots (fig. 3.5d). In many trabeculae of the grafts (micro)fractures were present (fig. 3.5d). The cellular elements of the graft were still present, but were necrotic and/or picnotic.

The chip grafts were locally interdigitated with the host bone bed, but there was no direct continuity between the dead graft trabeculae and the host trabeculae. The graft closely followed the host bone bed, indicating sufficient impaction. It was impossible to assess necrosis of the host bone bed because of the short postoperative follow-up period. At the graft-cement interface, cement had penetrated into the graft for about 2-3 mm, which resulted in close

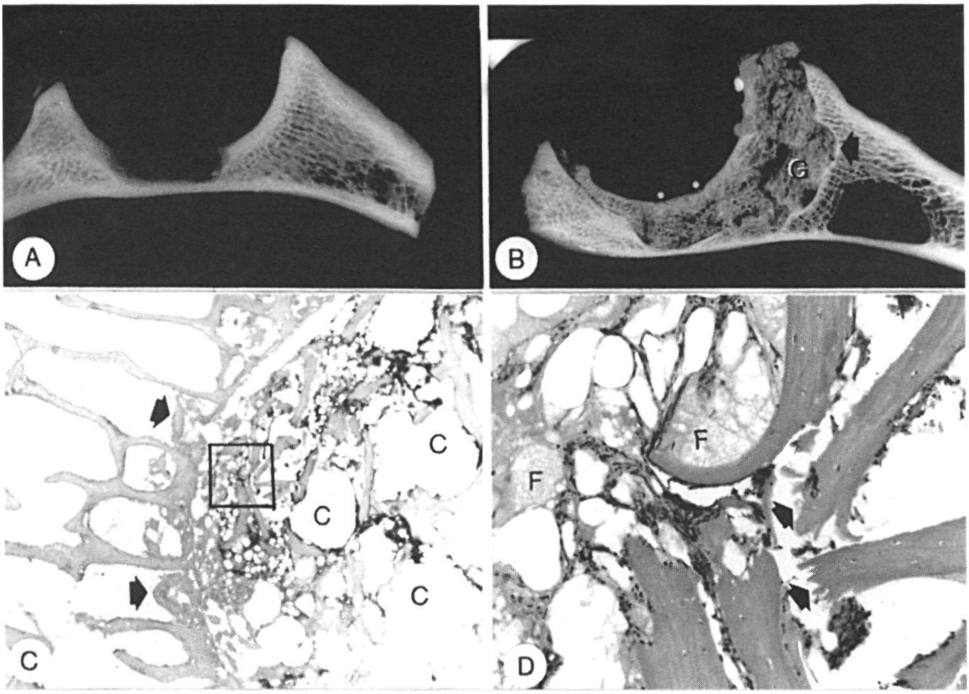

Figure 3.5. *Histology directly after surgery. A. X-ray of control specimen. x1.5. B. X-ray of a thick section through the defect. Note the thin sclerotic rim (arrow) at the interface between the graft (G) and host bone bed. x1.5. C. Low power histolgy of the defect. At the host-graft interface small fragments of bone were pressed inbetween the trabeculae of the host bone bed (arrows). The cement had penetrated into the graft material (C). x16. D. Magnification of the encircled area in C. Note the fractured trabeculae (arrows) and fibrin material (F) . x150.*

contact between the bone cement and dead graft trabeculae (fig. 3.5c). In all three specimens, the cement layer was intact.

3.3.2.2 3 weeks (goats 69B, 70B, 75B, 87H)

On the X-rays of the thick sections, there was no clear delineation between the graft and host bone bed (fig. 3.6a). An area of 0.5 to 1.5 mm of the host bone bed had become partially necrotic due to the surgical trauma. In the superior wall, this was mainly composed of trabecular bone, but in the medial wall the necrotic tissue was mainly composed of compact cortical bone. The necrotic bone became revascularized after three weeks and showed active bone remodelling (fig. 3.6b). Active periosteal bone appossition was present on the medial wall in all the specimens (fig. 3.6b). Sclerosis was seen in the HE section and in the fluorochrome sections of the host trabecular bone bed. Callous bone had been laid down on the preexisting trabeculae (fig. 3.6c,d). Consolidation of the graft with the host bone bed had occurred over large areas of the host-graft interface (fig. 3.6e,f). The area of sprouting revascularization had penetrated into the graft (fig. 3.7a,b), but it had not yet reached the graft-cement interface. This indicated that at the graft-cement junction necrotic graft trabeculae were still in direct contact with the penetrated cement but there was no fibrous interface membrane. In the transition zone between vital tissue and necrotic graft, loose fibrous tissue was found which mainly consisted of fibroblasts and histiocytes, also known as "osteoprogenitor mesenchyma". In the areas where this type of tissue had penetrated into the graft, we observed a concerted action of osteoclastic bone destruction of the graft and bone formation in the medullary space and in the remnants of the bone graft (fig. 3.7c,d). This predominantly comprised callous bone with disoriented collagen lamellae (fig. 3.6g,h). No differences were observed between graft in contact with cortical bone and graft in contact with cancellous bone. In one specimen (goat 75B) in which the medial wall had been perforated during surgery, bone graft

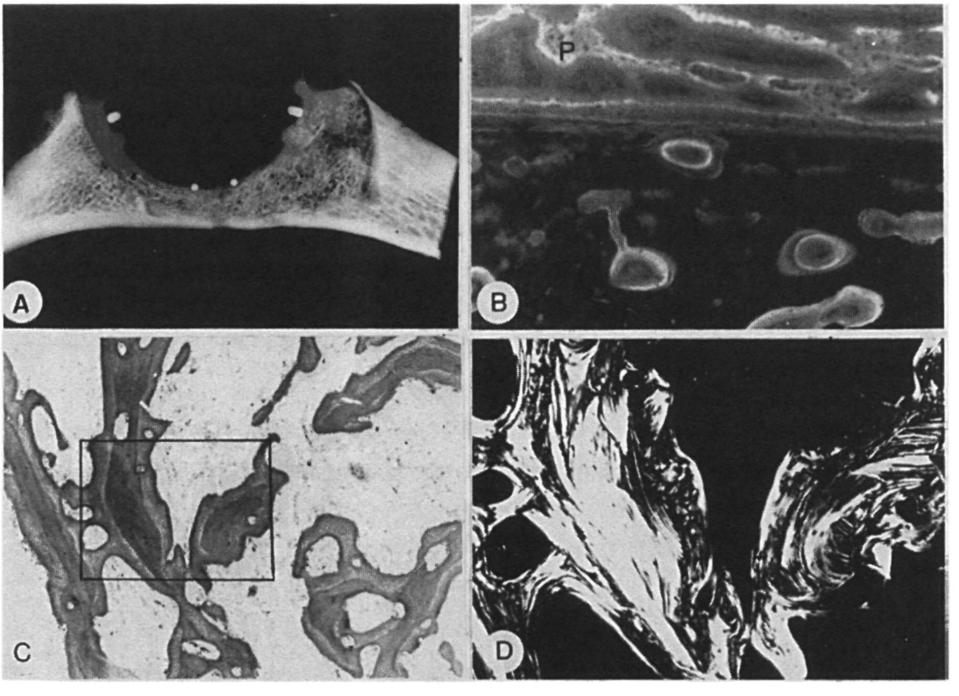

Figure 3.6. *Three weeks after surgery. A. The sharp deliniation between the host bone bed and graft was no longer visible. x1.5. B. Medial wall of the acetabulum. Fluorescence microscopy. Note the bone remodelling of the cortical bone and periosteal (P) bone apposition. x95. C. Trabecular host bone bed showing callous bone apposition after the operation. x40. D. Enlargement of the encircled area in C with polarized light. x100.*

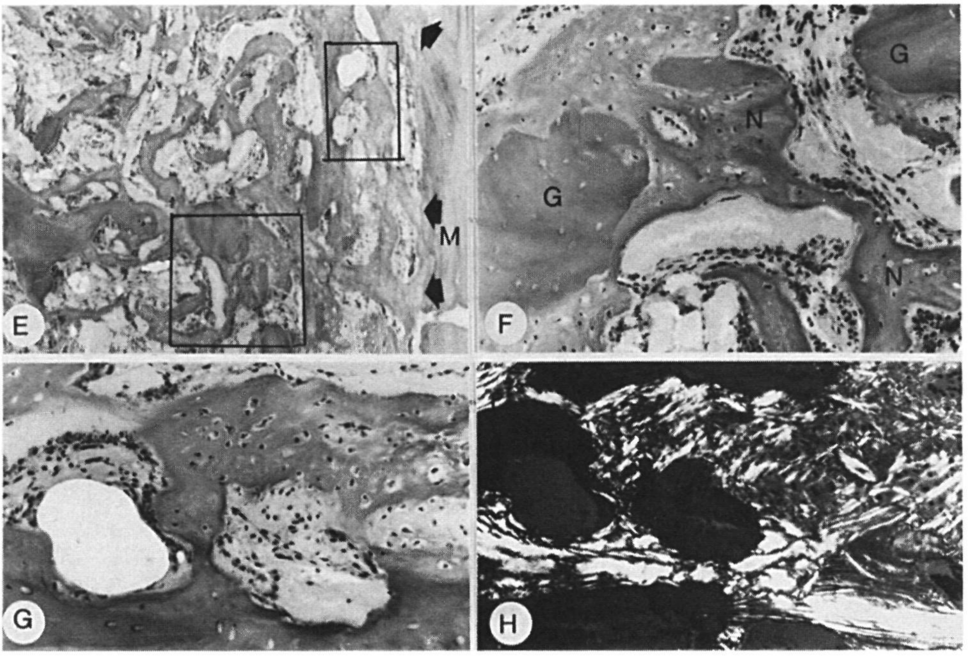

Figure 3.6. *(Continued). Three weeks after surgery. E. Graft in contact with the medial wall of the acetabulum (M). Arrows indicate sites where bone continuities were present between the medial wall and the graft. x50. F. Enlargement of lower encircled area in E, showing graft bone (G) and newly formed bone (N). x150. G. Enlargement of the upper encircled area in E. Note the callous bone. x150. H. Same location as in G with polarized light. x90.*

had come into direct contact with the intact periosteum (fig. 3.7e,f). Incorporation of the graft under the periosteum was not different from that at other locations.

3.3.2.3 6 weeks (goats 71H, 73H, 80H, 83H).

Periosteal bone activity was reduced. Local osteoclastic activity was present but the cortical bone of the medial wall was still about twice as thick as it was on the control side due to periosteal bone apposition. Consolidation between the host bone bed and graft was found over 100% of the contact zone in three goats (73H, 80H, 83H). The X-rays of the thick sections showed remodelling of the graft (fig. 3.8a). In the central part of the defect, the trabecular pattern of the graft could still be recognized. At the transition between the graft and viable bone, the presence of radiolucencies confirmed that during the incorporation process, parts of the graft had been resolved. The bone-forming activity at the graft-new bone junction had changed to the formation of lamellar bone instead of callous bone and showed reorganizing spongiosa with viable osteocytes on remnants of the graft (fig. 3.8c, d). Generally, the orien-

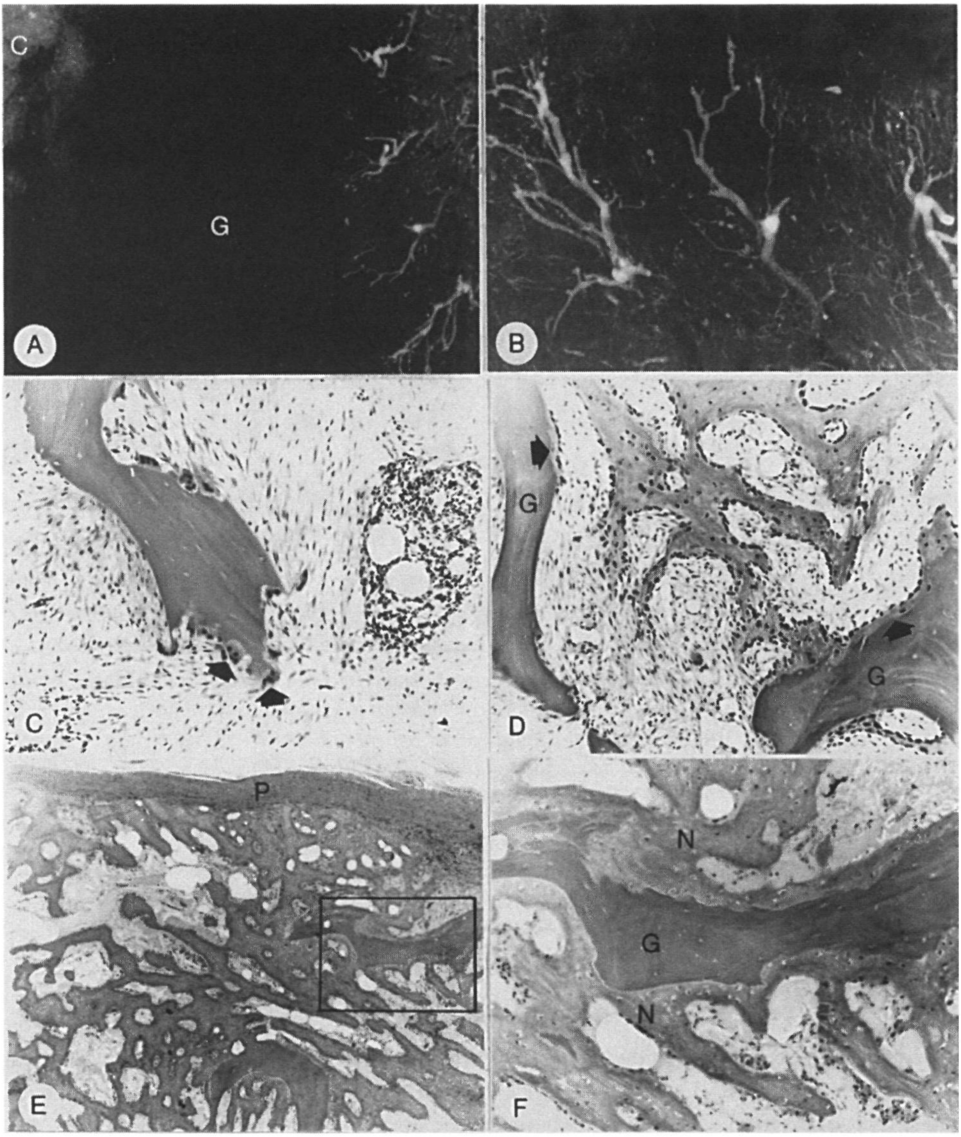

Figure 3.7. *Three weeks after surgery. A. Vascular sprouts penetrated into the grafted area (G) in the direction of the cement layer (C). x40. B. Enlargement of A. x80. C. Osteoclastic bone destruction (arrows) in an area of revascularization with loosely organized fibrous tissue. x150. D. Adjacent area in the section with bone formation on the surface of the graft (G; arrows) and in the fibrous tissue. x120. E. Graft incorporation under the periosteum (P) in the acetabulum with perforation of the medial wall during surgery. x30. F. Enlargement of the encircled area in E. N: new bone. x95.*

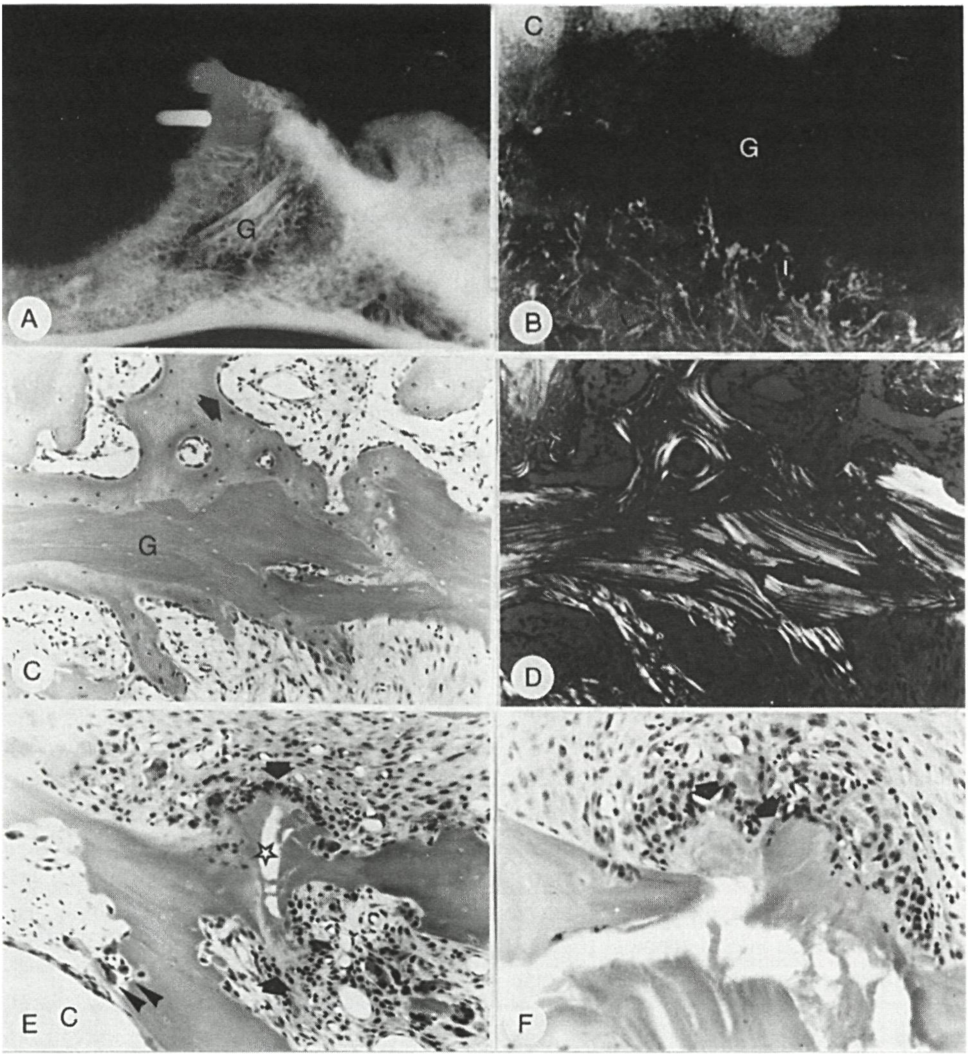

Figure 3.8. *Six weeks postoperatively. A. Complete consolidation of the graft (G) with the host bone bed. Radiolucent zones were found around the remnants of the graft (G). x4.5. B. Microangiography of the vacular ingrowth into the graft (G). C: cement layer. x40. C. Graft (G) with remodelling bone appositions. Bone formation converted to the formation of lamellar bone (arrow). D. Same location as in C, but with polarized light. x125. E. and F. Microcallous formation (arrows) at the transition between the individual pieces of graft (asterisks) in the vicinity of the cement layer (C). Note also the osteoclastic activity (arrow heads). x150.*

tation of the newly formed trabeculae had enabled load transfer from the cup to the host bone bed More than two thirds of the graft extending from the graft-host interface had become incorporated The zone of osteoprogenitor mesenchyma had moved towards the graft-cement interface Revascularization of the graft was also observed on the microangiograms which showed fronts of sprouting capillaries in the area of osteoprogenitor mesemchyma and clearly delineated avascular areas (fig 3 8b) Occasionally microcallous formation was observed in the area of revascularization of the graft (fig 3 8e,f) The microcallous was specifically located at the transitions between different pieces of graft material Vascular regions had reached the graft-cement interface and changed in the interface between the bone and cement In revascularizing areas, osteoclastic activity had initially caused a thin gap between the graft and cement (fig 3 9a) Apparently, parts of the soft tissue directly touching the cement layer had been replaced by bone and resulted in local areas of new bone-cement contact (fig 3 9c,d) In other areas, the soft tissue had remained unchanged and was present in the form of a fibrous tissue interface (fig 3 9b)

3.3.2.4 12 weeks (goats 81B, 82B, 84H, 88B)

In three goats (81B, 82B, 84H) there was no longer any clear host/graft junction in the cancellous part of the iliac bone which had contained most of the graft (fig 3 10b) Complete consolidation and remodelling had occurred in this area In the medial wall, reorganizing spongiosa, which showed simultaneous osteoclastic resorption and osteoblastic bone apposition, was in close contact with the original cortical host bone (fig 3 10c) The largest part of the graft in these three goats had become incorporated and showed reorganizing spongiosa with normal viable marrow (fig 3 10c) Vascular sprouting was observed which extended into the region where cement had penetrated the graft (fig 3 10d), but in all three specimens, local areas of the graft-bone interface had not yet become revascularized (fig 3 10c) In the vital areas of the interface, the same phenomena were found as in the 6-week group Local areas of new bone were in contact with the cement layer without the interposition of a soft tissue interface Where the interlock between the cement and graft was large, vital bone had deeply penetrated into the cement (fig 3 10e,f) However, in all three specimens a fibrous tissue interface was present over large areas of the cement-bone interface (fig 3 10a,b)

3.3.2.5 24 weeks (goats 61H, 64H, 66H, 72H)

Complete consolidation, incorporation and revascularization of the graft with reorganized spongiosa and viable marrow were observed in all four specimens Remnants of the graft were scarce or totally absent Fluorescence microscopy showed clear signs of remodelling with a denser trabecular structure which gradually decreased towards the graft-cement junction (fig 3 11b, 3 12g) Most of the spongiosa had viable bone marrow Moderate numbers of polymorphonuclear lymphocytes indicating a low grade infection were only found in one specimen (goat 64H, fig 3 12a,b) No bone destruction was seen in this goat At the graft-cement junction, all four goats showed viable trabecular bone over the whole contact area and an interfacial membrane was present between the bone and cement However, areas of direct

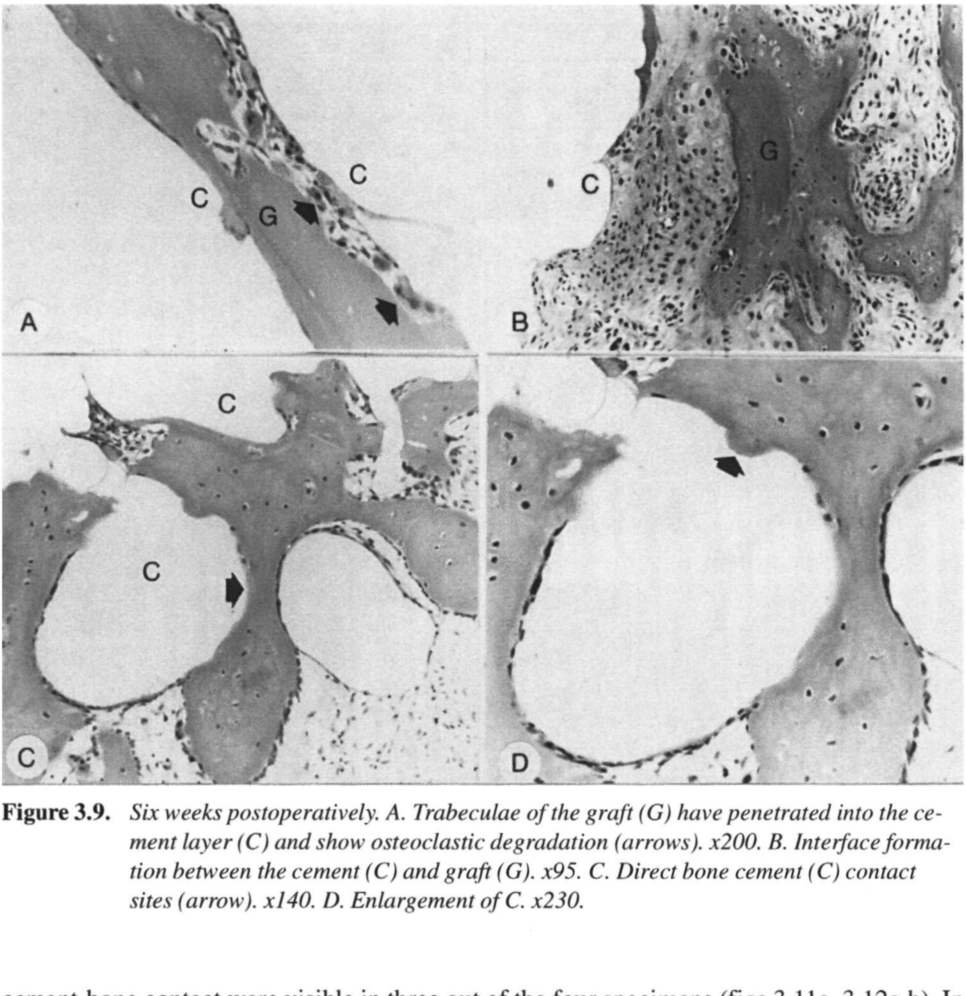

Figure 3.9. *Six weeks postoperatively. A. Trabeculae of the graft (G) have penetrated into the cement layer (C) and show osteoclastic degradation (arrows). x200. B. Interface formation between the cement (C) and graft (G). x95. C. Direct bone cement (C) contact sites (arrow). x140. D. Enlargement of C. x230.*

cement-bone contact were visible in three out of the four specimens (figs 3.11a, 3.12g,h). In the acetabulum of goat 64H, the interface membrane was thicker and contained many sheats of mononuclear histiocytes (fig. 3.12c,d). The interface of the other specimens consisted of fibrocartilage (fig. 3.12e) or dense fibrous tissue with scarce granulation tissue (histiocytes, foreign body giant cells) on the cement side.

3.3.2.6 48 weeks (goats 56RB, 57RB, 59RB, 62H)

Two goats (57RB and 59RB) showed complete loosening of the acetabular cup and femoral stem with massive loss of bone stock and resorption of the acetabular allograft. No infection could be detected either clinically or by cultures. Therefore, these goats were excluded from any further histological analysis. In the two remaining acetabuli (56RB and 62H) the histology was similar to that in the 24-week group. An interfacial membrane had developed at the

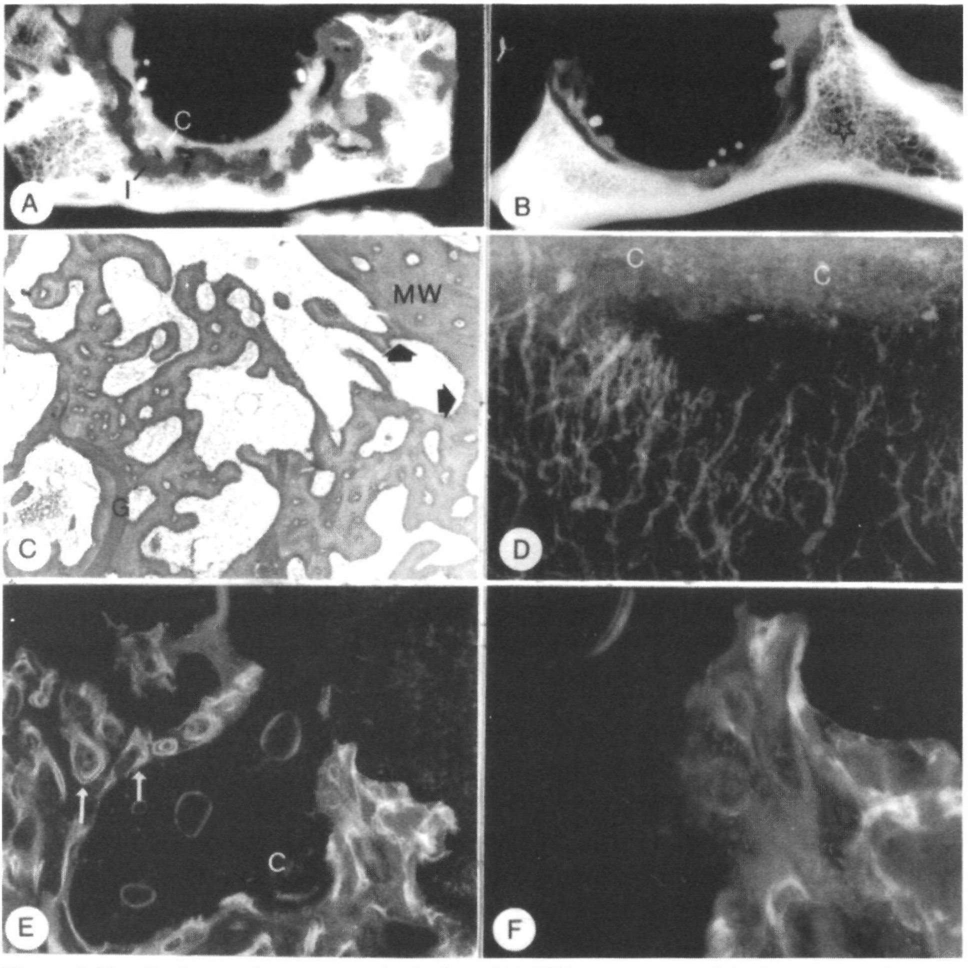

Figure 3.10. *Twelve weeks postoperatively. A. and B. Different aspects of the bone cement interface. In A. a thick interface (I) has developed between the graft and cement (C). B. direct bone-cement contact and a completely reorganized defect (asterisks) in the superior wall of the acetabulum. x1.5. C. Reorganizing spongioza in the superior acetabular wall. Only remnants of the graft (G) were present in the bone. Consolidation with the medial wall (MW) was present (arrows). x40. D. Vascular infiltration of the graft into the cement (C). x40. E. Calcein green labelling (arrows) of the bone in direct contact with the cement layer (C). x30. F. Enlargement of E. x100.*

graft-cement junction in both goats (fig. 3.11c,d). It mainly consisted of loose fibrous tissue. On the cement side there were some focal areas of thin granulation with foreign body giant cells and histiocytes. The trabeculae were all viable without any signs of osteoclastic resorp-

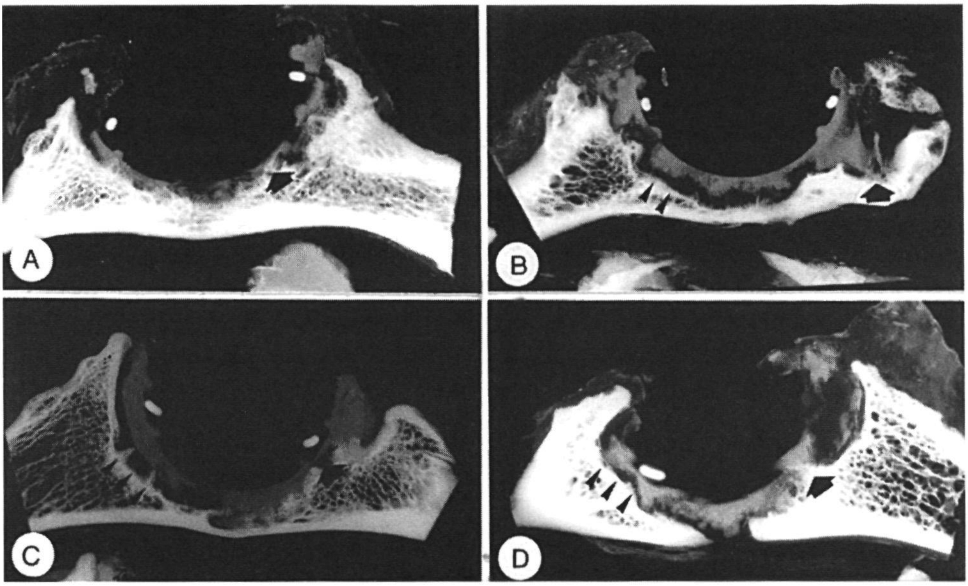

Figure 3.11. *X-rays of thick sections after 24 weeks (A. and B.) and 48 weeks postoperatively (C. and D.). Note the areas of direct bone-cement contact (arrows) and interface formation (arrowheads). x1.5.*

tion. As was also the case at 24 weeks, several protrusions of trabecular bone crossed the interfacial membrane and directly connected the cement cuff with the cancellous bone (fig. 3.11c, d). The trabeculae adjacent to the membrane on the cement surface appeared to be thickened and showed a denser pattern. This was interpreted as a sign of more active remodelling, probably as a reaction to instability of the cup.

3.4 Discussion

3.4.1 Consolidation

For practical reasons, the general use of morsellized cancellous allograft bone is to be preferred above cortical solid allografts in reconstruction surgery for all types of defect because of the intimate contact that can be obtained with the host bone bed after impaction. This was confirmed in our study. The graft material closely followed the configuration of the host bone bed. This close contact was expected to be beneficial for rapid consolidation, as opposed to reconstruction with structural bone blocks, which would fit the bone bed relatively loosely and possibly have a negative influence on consolidation.

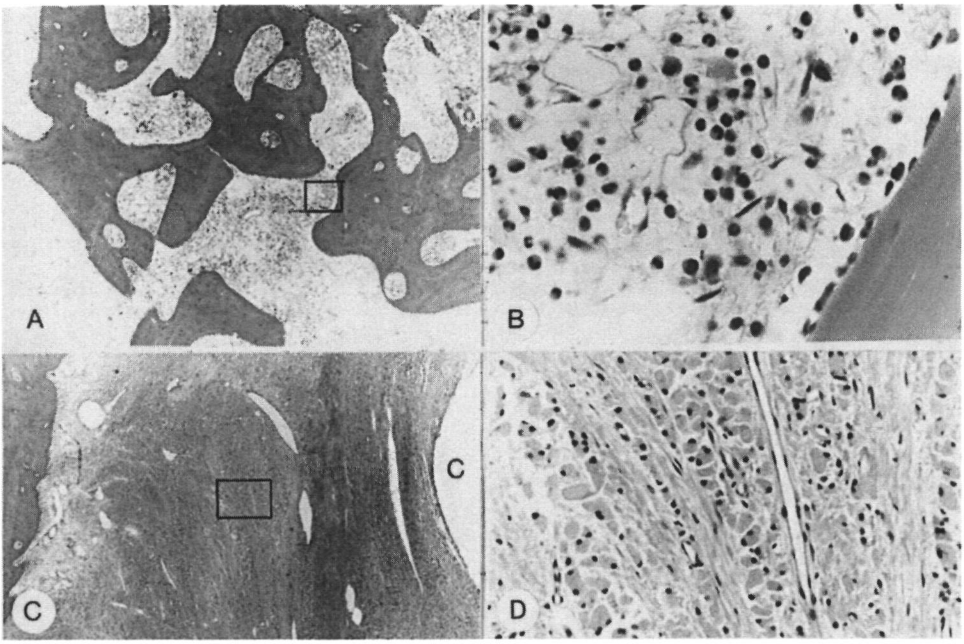

Figure 3.12. *Histology of bone-cement contact after 24 weeks. A. A typical specimen (G64H) with many polymorphonuclear leucocytes in the medullary region of the grafted bone. x45. B. Enlargement of the encircled area in A. x375. C. Interface of 2.5 mm thickness of specimen G64H after 24 weeks. x30. D. Enlargement of the encircled area in C. showing many mono- and poly-nuclear macrophages throughout the interface. x140.*

It is not possible to compare the time needed for consolidation in our goat experiment to that in the human revision situation, because the biological charateristics of our animal model differed from those involved in revising a loosened cemented hip arthroplasty. In addition the possibly avascular, sclerotic surface of the recipient (human) bone bed after a failed cemented implant was absent in our model. Thus, in theory, the process of consolidation between the host bone bed and the graft, which only took 3 weeks in our animal model, would probably take longer in the human revision situation.

3.4.2 Incorporation

In many animal experiments conducted over the past decades, autografts have shown to be superior to allografts from a biological point of view, which has been expressed in the amount and rate of graft incorporation (Burwell 1969, Campbell 1953, Heiple et al. 1963). The rates and extents of allograft incorporation are thought to vary considerably and are, in fact, unpredictable; allograft failure may be the consequence of an immune response, as was illustrated in a report on massive retrieved allografts (Enneking and Mindell 1991). There is

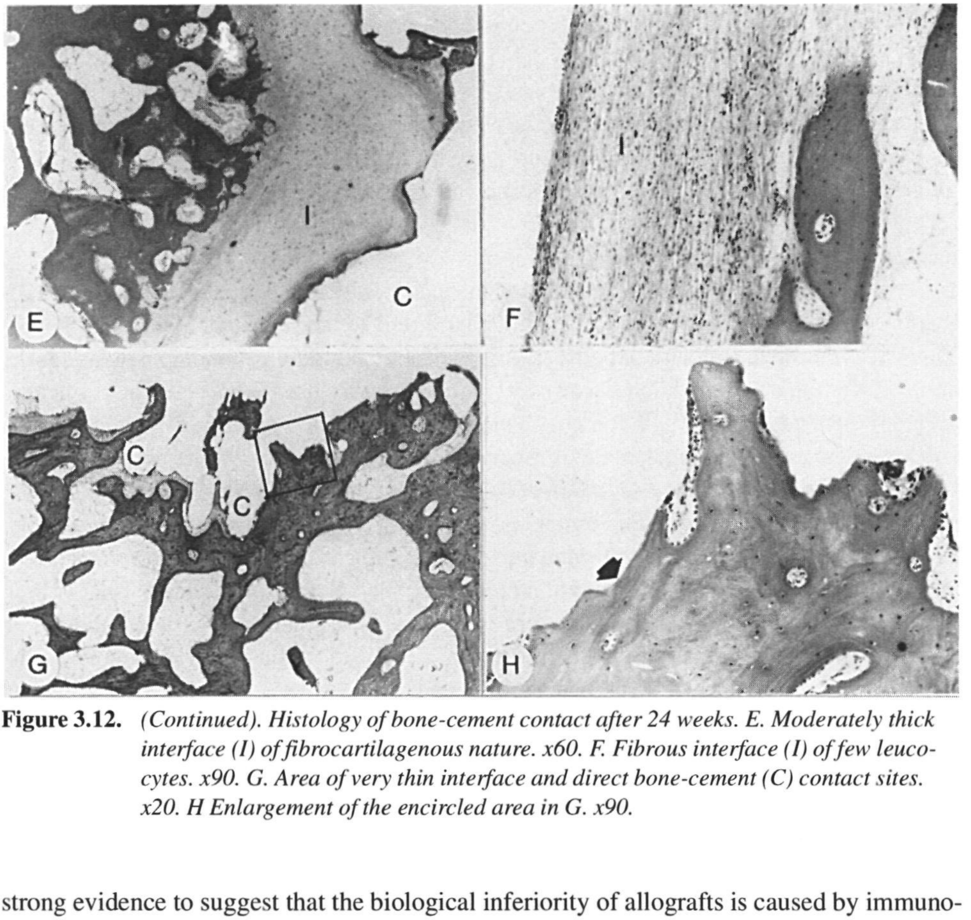

Figure 3.12. *(Continued). Histology of bone-cement contact after 24 weeks. E. Moderately thick interface (I) of fibrocartilagenous nature. x60. F. Fibrous interface (I) of few leucocytes. x90. G. Area of very thin interface and direct bone-cement (C) contact sites. x20. H Enlargement of the encircled area in G. x90.*

strong evidence to suggest that the biological inferiority of allografts is caused by immunological disparity between the host and graft, which causes cell-mediated responses (Friedlander 1991, Goldberg et al. 1989, Stevenson et al. 1991). However, the immunogenicity of allograft bone is known to be markedly reduced by freezing (Brooks et al. 1963, Mankin and Friedlander 1989).

In our experiment we did not perform histocompatibility matching. The rate and extent of incorporation of all the non-infected grafts were comparable so it is unlikely that immunological factors influenced the process. However, it is possible that the massive infiltration of polymorphonuclear lymphocytes in goat 64H (24 weeks), which was considered to represent low grade infection, might have been an immunological response, although this phenomenon was unique in our experiment and complete incorporation occurred.

These results and those previously published on femoral revisions with morsellized allograft chips (Schreurs et al. 1994) have shown that this type of bone material has a high capacity to incorporate. In our study a fairly consistent pattern was observed in the speed and mode of incorporation and revascularization during the first 12 weeks. The process of graft incorporation involved simultaneous bone apposition and resorption in the early phase of graft incorporation After this period, viable reorganized lamellar bone was found throughout the original graft

It is hypothesized that a prerequisite for successful incorporation is good impaction of the graft material, which will possibly also influence the initial stability of the reconstruction As in our experiment all the reconstructions showed incorporation, it might be concluded that sufficient initial stability could be created for incorporation using the surgical technique applied

The sequence of biological events during the incorporation of structural cancellous grafts is similar to that with morsellized allograft chips (Friedlaender 1987, Goldberg and Stevenson 1987) The open structure of both types of graft should promote more rapid revascularization than compact cortical bone However, retrieval studies have indicated that a structural allograft does consolidate with the host bone bed, but that incorporation is confined to the outer zone of the graft (Enneking and Mindell 1991) The remaining inner necrotic zone of the structural graft may give rise to failure by fatigue damage in the long-term

There may be mechanical and biological differences in the incorporation characteristics between structural cancellous grafts and morsellized chip grafts It is well-known that mechanical factors influence the incorporation process of bone grafts (Friedlaender 1987) However, correlating the weight bearing pattern of the goats with their histological findings, we could not establish whether weight bearing had influenced the mode and extent of consolidation and incorporation In the specimens evaluated after 3 weeks, one goat (87H) had not used the limp at all and no difference was observed in the early process of consolidation In the 24-week group, one goat (64H) had only supported the hip incidentally for 6 weeks and still full graft incorporation had occurred although the cup appeared to be slightly unstable with dense fibrous tissue at the graft-cement interface

It can be speculated that the following factors might be involved in graft incorporation 1) The density of trabecular bone is higher compared to non-impacted structural cancellous graft material This type of bone could contain more growth factors of the TGF-ß- and BMP-family Impacted bone graft also has a relatively large surface area for osteoclastic bone destruction, which in combination with the growth factors could account for an increased bone-inducing capacity The release of the growth factors from the graft may even be more facilitated by the microfractured surface of the graft material that is a result of the impaction proces 2) In theory, the incorporation of impacted bone graft can be compared to fracture repair Impaction does not produce complete stability between the individual pieces of graft Micromotions within the graft material could stimulate host cells to bone formation and this may result in rapid consolidation and incorporation of the graft Further research is needed to clarify these hypotheses

3.4.3 Graft-cement interface

The bone cement did not seem to have any adverse effects on the incorporation process of the bone grafts, although some authors (Samuelson et al 1990) have expressed concern that it might. Roffman et al (1983) did not observe any adverse effects of bone cement in a dog model. After 6 months, full consolidation and incorporation of autologous cancellous bone grafts were found in an acetabular defect which had been covered with bone cement. In our study with morsellized cancellous allografts, we observed a comparable extent of incorporation and consolidation even though the goats were evaluated at much earlier intervals. Although the cement layer did not affect the incorporation process, events at the graft-cement interface may have been responsible for the cases of late loosening in this goat model. We found that where the new vascularity had reached the graft-cement interface, the graft has been resorbed by osteoclastic activity. Part of the resorbed bone had been replaced by a thin loose fibrous tissue membrane and part had been replaced by host bone. This process of graft replacement resulted in a decrease of the interlock between the graft-new bone mixture and the cement layer. In most of the animals, scattered areas of vital bone remained in intimate contact with the cement layer, but an organized fibrous tissue layer, a common phenomenon around stable implants (Draenert 1990, Linder and Carlsson 1986), was found at other locations. Particulary in the goats followed-up for 24 and 48 weeks, the relatively thin fibrous tissue had developed into a dense fibrous tissue interface with mononuclear histiocytes and foreign body giant cells which indicated micromovements and cup instability (Goldring et al 1983). Also the clinical score correlated with the histological evidence of loosening.

The clinical behaviour and mechanical environment of the prostheses after surgical reconstruction are quite different between goats and humans. For instance, there are differences in the loading regime after surgery, the goats were allowed full weight-bearing after two days. In addition, the behaviour of the goat is such that it can be expected to exert greater mechanical forces on the cement bone interface than a human. Another major difference between goats and humans is the size of the defect. In the relatively small acetabulum of the goat the cement layer was much thinner than that applied to humans. This might have induced high peak stresses at the bone-cement interface. Although the principal loosening scenarios for cemented total hip replacement (Huiskes 1993) are also applicable to a prosthesis in the goat, the above described differences may be responsible for the different time scales. The dynamic bone interface stresses which can lead to disruption of the cement-bone bond may have been able to cause more damage owing to insufficient cement in some specimens. The other scenario of reaction to wear particles might have also played a role because we found foreign body giant cells in the interfaces, defects in the cement mantle might have contributed to this situation. In general, the cement layer was fairly thin and in some of the goats even completely lacking at several places so that the graft was in direct contact with the cup and thick fibrous tissue had developed in between. Although it was extremely difficult to correlate good performance with the integrity of the cement layer, it is likely that the condition of the cement mantle played a role in the early loosening process. During surgery the cup was cemented without pressure after the graft had been impacted with a slightly oversized socket trial prosthesis Pressure might have helped to create a continuous cement mantle with a better cement-bone interlock

Infection is the most frequent and devastating complication in bone allograft surgery with an average rate of about 10% in humans (Lord et al 1988) In our series of 23 goats, we had three cases (13%) with infection proven by positive cultures and/or histological sections A considerable proportion of the grafts had been resorbed or showed massive infiltration of inflammatory cells The most probable cause for the higher infection rate in allografts is undetected contamination during storage and transport, although also the extent and duration of the operation can play a role

3.5 Conclusion

Acetabular reconstruction with impacted morsellized cancellous allografts in cemented hip arthroplasty in the goat, has a high capacity to consolidate and incorporate, showing a consistent pattern The incorporation process moved like a front from the host bone bed towards the graft-cement junction and showed a simultaneous process of bone resorption and apposition As complete graft incorporation was noted in all the animals, sufficient initial stabilty of the reconstruction seemed to have been achieved At 24 and 48 weeks, clear signs of cup instability were present both histologically and clinically in the majority of animals This loosening process by mechanical stress and particle reactions at the bone-cement interface was possibly enhanced by insufficient thickness of the cement mantle The infection rate was 13% and led to graft resorption and total failure

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CHAPTER 4

Mechanical stability of cemented acetabular cups in acetabular reconstruction with impacted morsellized cancellous allograft: an animal study

4.1 Introduction

Many articles now appear in the literature reporting good clinical results of acetabular reconstruction with bone grafts in case of bone stock loss, associated with the loosening process of hip arthroplasty (Oakeshott et al. 1987, D'Antonio et al. 1989, Emerson et al. 1989, Olivier and Sanouiller 1991, Gates et al. 1990) Several different bone grafting techniques are used, depending on location and severity of bone stock distortion, and preference of the surgeon (Chandler and Penenberg 1989 , Gerber and Harris 1986, Jasty and Harris 1990, Wilson et al. 1989, Brien et al. 1990, Samuelson et al 1990, Slooff et al 1984) At the Orthopaedic Department of the University Hospital Nijmegen, acetabular defects in revision hip surgery have been reconstructed with impacted morsellized cancellous allografts from the bone bank with a cemented cup since 1979.

The purpose of this study was to evaluate the stability of the cemented cups, initially and later postoperatively in acetabuli, reconstructed with impacted morsellized cancellous allografts. For that purpose an animal model was developed. Stability was determined in loading tests, using Roentgen-Stereophotogrammetric Analysis (RSA) to determine motions

4.2 Material and methods

4.2.1 Test animals

Twelve skeletally mature Dutch milk goats (Capra Hircus Sana), about 2 years old and weighing between 46.3 and 77.4 kg (average 58.9 kg) were used in this study (fig 3.1). The allografts were harvested, under sterile conditions, from another goat's sternum, packed as small chips 1/4-1/2 cm diameter in sterile bags after cultures had been taken and stored at -70 degrees Celsius No histocompatibilty matching had taken place Just before use they were thawed in physiological saline.

4.2.2 Surgical technique

Anaesthesia was induced by intravenous Nembutal (30mg/kg) and atropine 0 5 mg and maintained via endotracheal intubation with a mixture of nitrous oxide, oxygen and halothane in a closed circuit After 500 mg ampicillin iv. had been administered as antibiotic prophylaxis, and routine aseptic measures had been taken, the right hip was exposed via an antero-lateral approach. Total capsulectomy and femoral neck osteotomy were performed. The acetabular cavity was cleared of soft tissue and reamed to a diameter of 29 mm, avoiding to penetrate the medial wall (fig. 3.2a). With a speed burr, a standard defect was made in the dorso-cranial part of the acetabulum, including the periferal rim, with a maximal depth of 1.5 centimeters (fig. 3.2b). Many small burr holes (2mm) were made in the cortical bone of ilium and acetabular cavity, to stimulate vascularization of the recipient bone bed (fig. 3.2c).

After cleaning and drying, acetabular cavity and defect were filled with grafts (fig. 3.2d), which were impacted with a 25 mm diameter socket trial prosthesis, in such a way, that the socket was localized in the anatomical position, attempting to restore the original center of rotation as good as possible (fig. 3.2e). Except for the caudal and ventral walls, the acetabular cavity was completely covered with a layer of allografts, and a 22 mm polyethylene cup (Mathys, Bettlach, Switzerland) was cemented in place (fig. 3.2f). In the cup, 4 small tantalum pellets (0.8mm) had been inserted preoperatively at the dome of the cup through small drill holes, and fixated with glue. Two tantalum pellets had also been inserted at opposite sides in the rim of the cup (fig. 4.1). Next, the femoral canal was reamed and a plastic plug (Allopro) was inserted, whereafter the femoral component was cemented in place (fig. 3.2g). The femoral component was made of a cobalt-chromium alloy with a 16 mm head (Mathys, Bettlach, Switzerland) (fig. 4.1). CMW low-viscosity cement was used. The hip was reduced and the wound closed in layers.

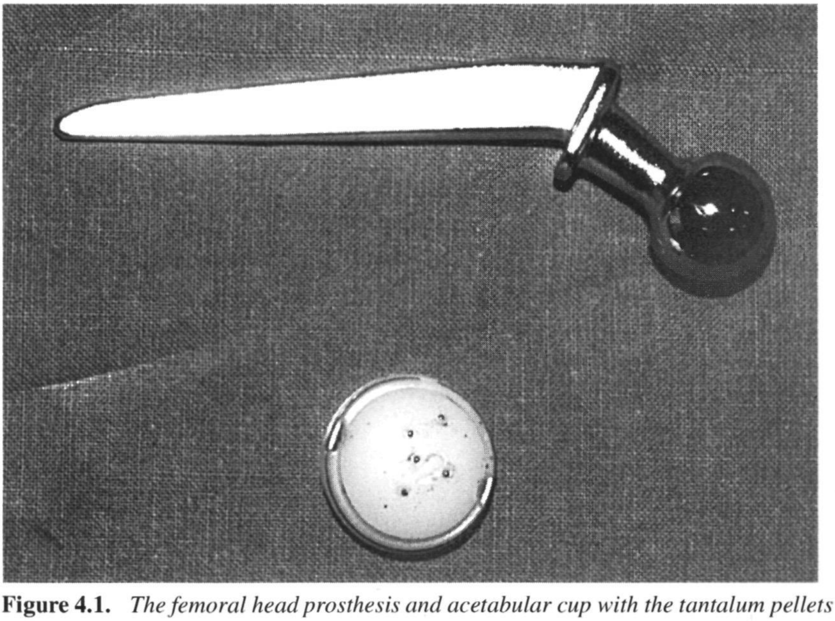

Figure 4.1. *The femoral head prosthesis and acetabular cup with the tantalum pellets*

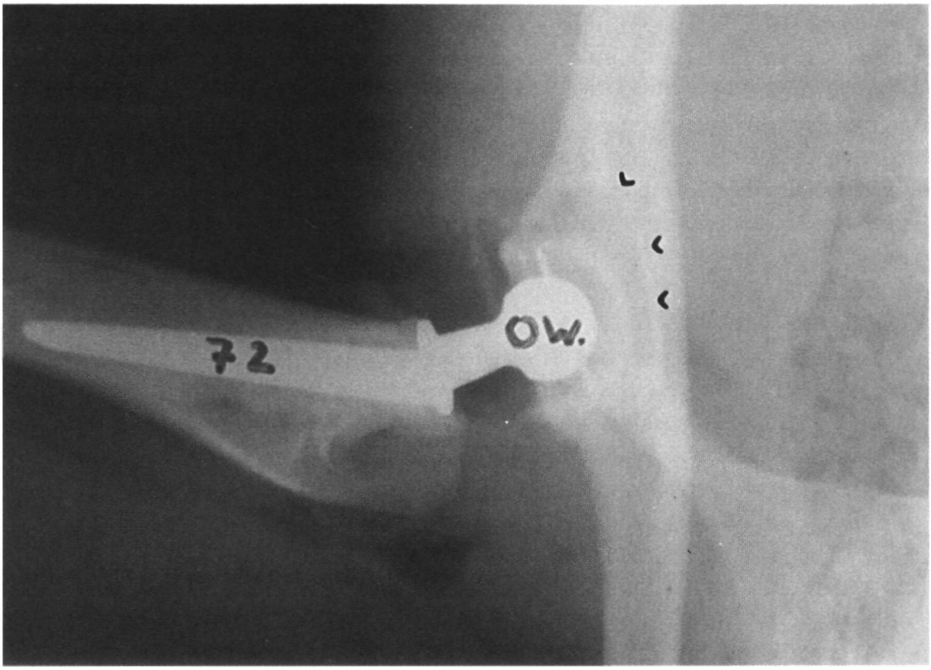

Figure 4.2a. *Antero-posterior radiograph of right hip in-vivo immediately after implantation. The grafted part of the acetabulum is clearly visible (arrowheads)*

4.2.3 Postoperative treatment

Immediately after the operation, standardized antero-posterior pelvic radiographs were made (fig. 4.2).

The goats were immobilized during 2 days in a special hammock, in which both hind-legs were unloaded. Thereafter free weight bearing and mobilization were allowed.

The weight bearing pattern was assessed at 3,6,12,24,48 weeks using a grading schedule according to Ypma (1981) (table 4.1)

Radiographs were made just before harvest or when dislocation, fracture or premature loosening was suspected.

4.2.4 Harvest technique

Three animals were sacrificed immediately after the operation and three at 3,12 and 48 weeks, each using an overdose of pentobarbitone. The pelvic bones were exarticulated in symphysis and sacro-iliac joint. Care was taken to leave the pelvic half intact for anatomical re-orientation during later mechanical testing (fig. 4.3). Femoral and acetabular components

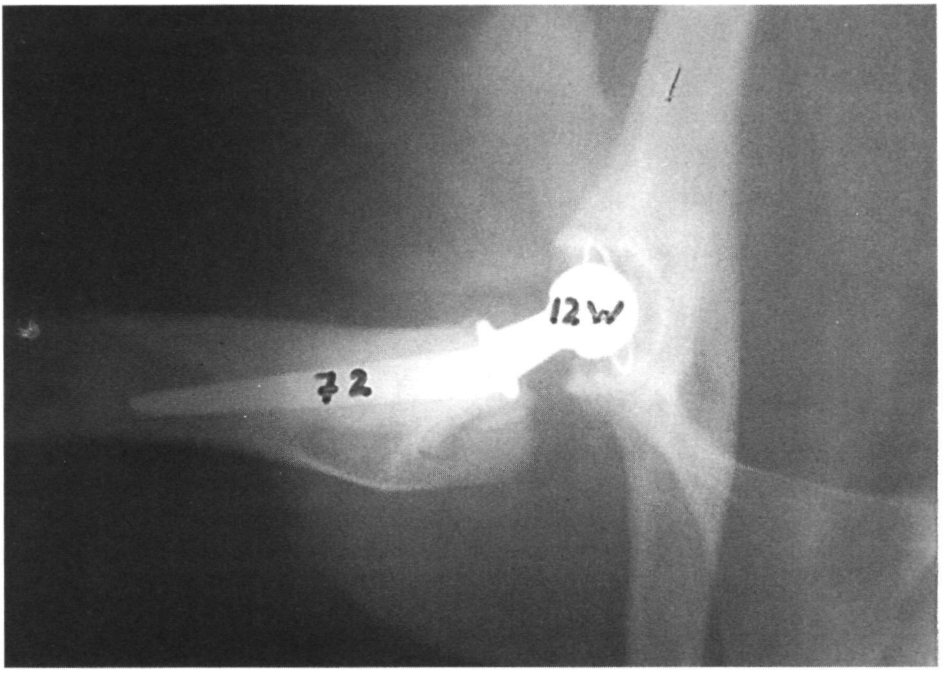

Figure 4.2b. *After 12 weeks the acetabular bone graft can not be distinguished anymore from the host bone bed and is considered radiographically incorporated*

were inspected and tested manually for stability which was graded according to a grading scale (table 4.1). Radiographs of the pelvic bones were made in two directions for radiographic assessment of cup fixation and graft consolidation and incorporation (fig. 4.4 a,b,c,d). When there was gross purulence at harvest, or components were fully luxated, cultures were taken and further analysis was renounced.

The specimens were stored at -20 degrees Celsius.

4.2.5 Mechanical testing

Before testing each specimen was thawed at room temperature overnight. The specimens were cleaned from all soft tissues. At standard locations in iliac, ischial and pubic bone, 3 clusters of 4 tantalum pellets (0.8 mm) each, were inserted through drill holes.

The bone/prosthesis specimens were mounted in an MTS testing machine and fixed with cement (FastAcryl Rose ®) in a standard way (fig. 4.5 a,b). Relative to the horizontal position of the iliac bone and a vertical position of the intact parts of the acetabular rim, the direction of the applied force was 30 degrees in cranio-caudal direction and 30 degrees in medial-lateral direction (fig. 4.6 a,b). This load direction was chosen, because the grafted cranial,

Table 4.1. *Clinical score*

Follow-up (weeks)	Goat number	Weightbearing 3	6	12	24	48 (weeks)	Fixation Stem	Cup	Complications
0	56LB						3	3	
0	57LB						3	3	
0	59LB						3	3	
3	69B	4					3	3	
3	70B	3					3	3	
3	75B	3					3	3	P
12	81B	3	4	4			3	3	
12	82B	4	4	4			3	3	
12	88B	4	2	1			1	1	I
48	56RB	3	4	4	4	1	0	3	
48	57RB	3	4	2	2	2	0	0	
48	59RB	3	4	3	2	1	0	0	

Weightbearing (according to Ypma (1981))
0 = not used at all
1 = supported incidentally
2 = loaded in standing position and incidentally while walking
3 = loaded in standing position and walking but with a limp
4 = normal walking and standing pattern

Fixation at sacrifice (according to Ypma (1981))
0 = completely loosened and extractable without any force
1 = slightly movable
2 = stable but extractable by hand
3 = fully stable.

Complications
P = medial wall perforation peroperatively
D = dislocation
I = infection proven by positive culture
F = femoral fracture

dorsal and medial walls of the acetabulum were maximally loaded and because it approached the physiological load in-vivo during gait (Bergmann 1984). Load was applied step-wise from 0 to 700 N and again unloaded (fig. 4.7). The maximal load applied in our experiments was 700N, which is 116% of average body weight of the goats, equalling the

Figure 4.3. *Radiograph of pelvis half harvested immediately after operation. Cemented acetabular cup augmented with impacted cancellous bone chips*

maximal load on the hip in sheep in-vivo, during normal gait (Bergmann 1984). Each loading period lasted 10 minutes. Before loading, 10 minutes after 700N loading was applied and 10 minutes after subsequent unloading, stereo-radiograms were made for Roentgen- Stereophotogrammetical Analysis (RSA) as developed by Selvik (1989). Stereo-radiograms were evaluated on an Aristomat-digitizer and with the RSA-computer program "Kinema" it was possible to establish 3D-rotations and -translations of the cup relative to the pelvic bone. The origin of the coordinate system was determined by the 4 pellets in the dome of the cup (fig. 4.6 a,b). Translations along the X-axis (medial-lateral), Y-axis (cranio-caudal) and Z-axis (dorsal-ventral) were established, together with rotations around these axes. Each measurement of the stereo-radiograms was performed 3 times. After unloading, elastic recovery occured, resulting in permanent translations and rotations of the cup.

Figure 4.4a. *Antero-posterior and lateral-medial radiographs of pelvis half of goat 58 LB harvested immediately postoperatively. The impacted bone chips can be clearly distinguished from the host bone with an irregular pattern and without trabeculation. No radiolucency at the graft-cement interface.*

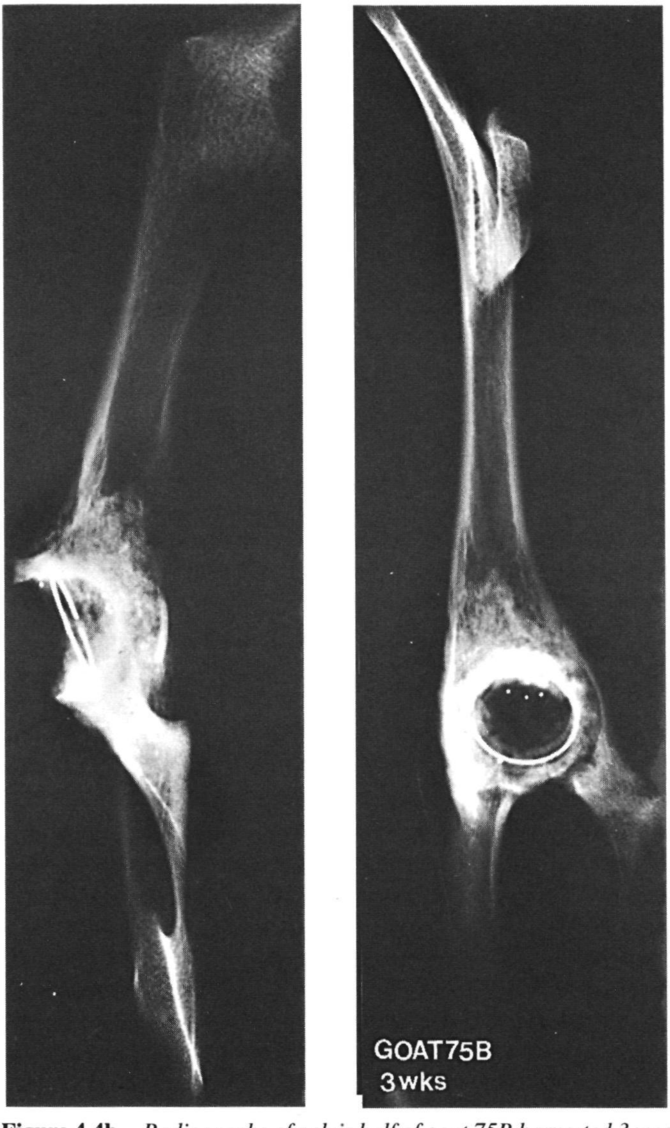

Figure 4.4b. *Radiographs of pelvis half of goat 75B harvested 3 weeks postoperatively. The grafted part has an irregular pattern without trabeculation. No radiolucency at the bone-cement interface.*

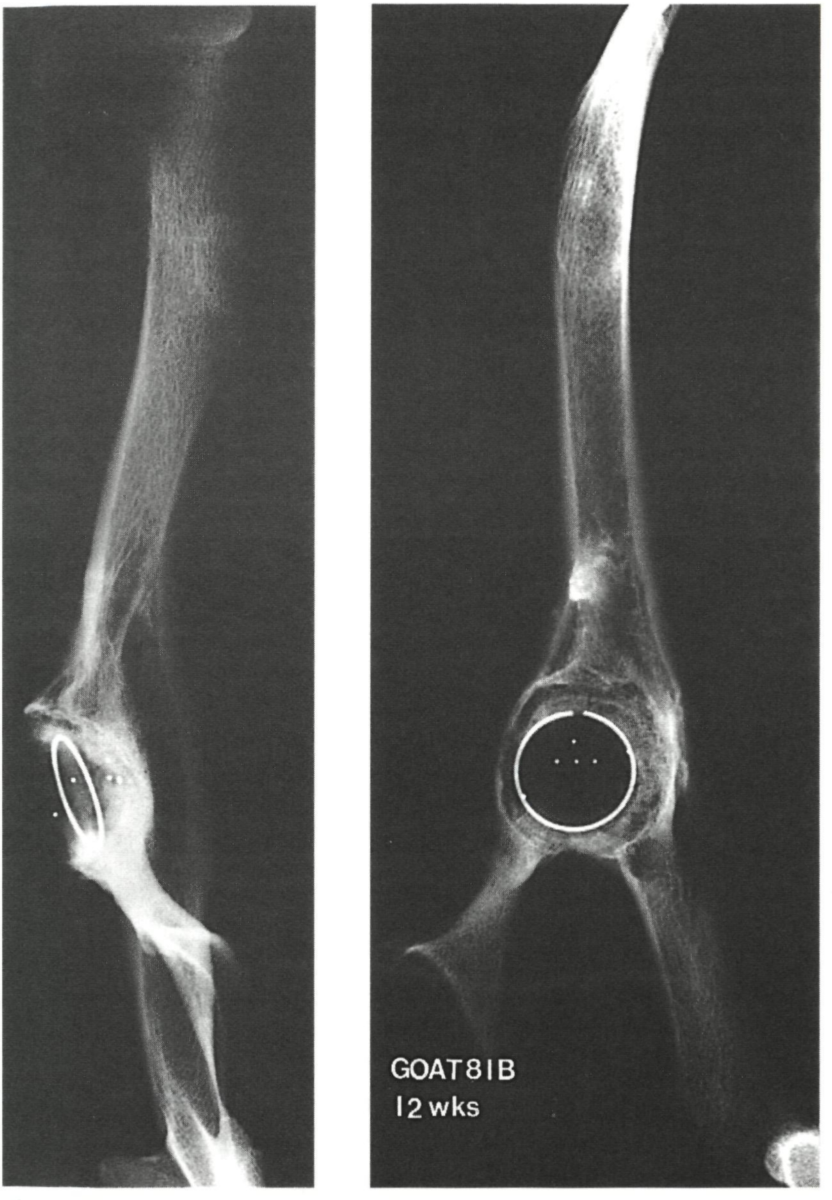

Figure 4.4c. *Radiographs of pelvis half of goat 81B harvested 12 weeks after operation. The impacted bone chips cannot be distinquished from the surrounding host bone. A continuous trabecular pattern has developed throughout the graft bridging the former graft-host junction. No radiolucency at the graft-cement interface*

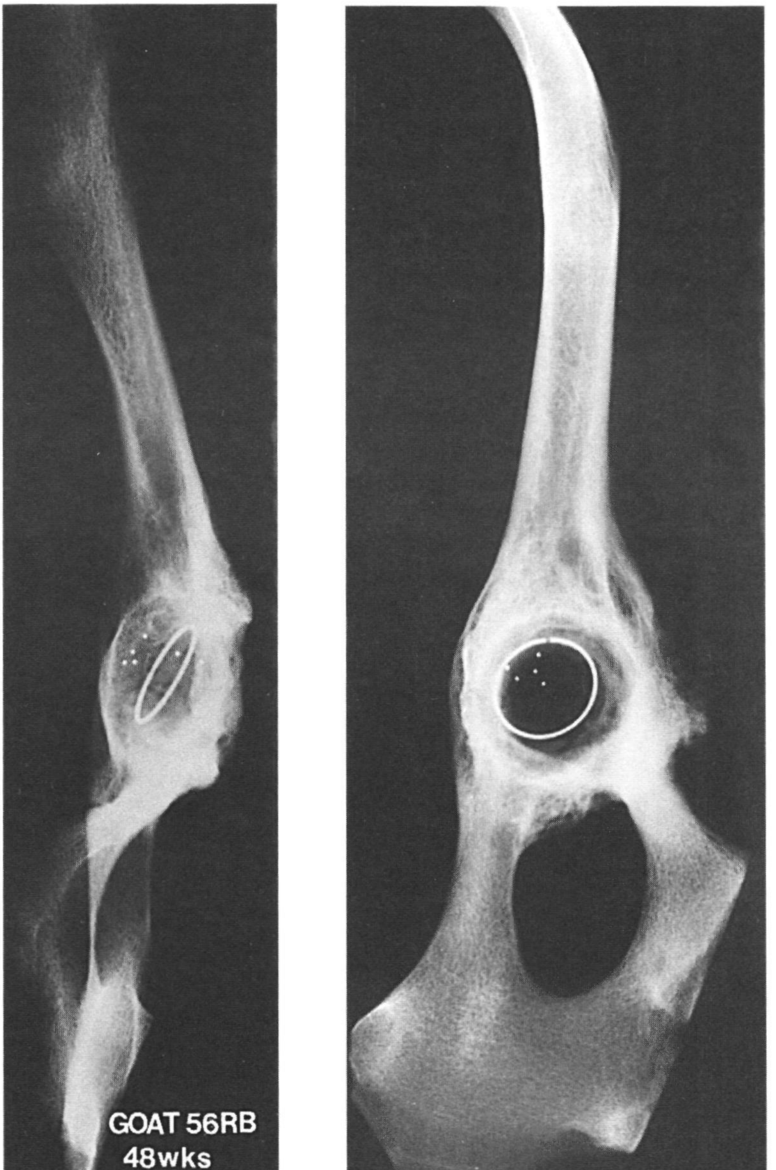

Figure 4.4d. *Radiographs of pelvis half of goat 56RB harvested 48 weeks postoperatively. The cup has migrated in cranial-medial direction with resorption of the bone graft. There is a clear radiolucent demarcation visible at the bone-cement interface*

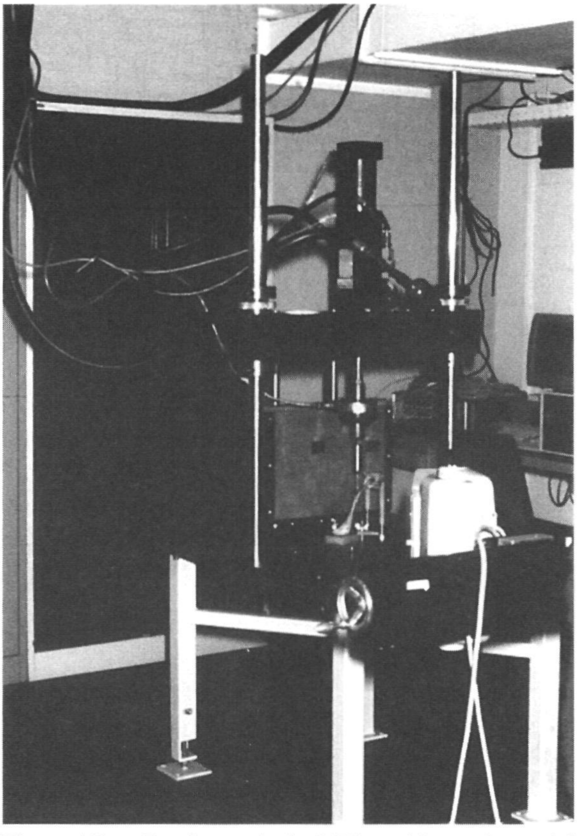

Figure 4.5a. *Test line up in the MTS machine and one of the roentgen tubes for stereo radiographs*

4.3 Results

4.3.1 Clinical and radiological performance

All animals with follow-up 3, 12 and 48 weeks were ambulated and allowed full weight-bearing after two days in a hammock. Three animals (goats 56LB, 57LB and 59LB) were sacrificed immediately after operation to assess initial stability.

Goats 57RB and 59RB showed complete loosening of the cup at sacrifice after 48 weeks, without signs of infection as proven by negative cultures. Goat 88B (12 weeks) had developed an infection with staph. epidermidis, established in culture. In goat 75B (3 weeks) a perforation of the medial wall was made during the operation.

The average clinical scores according to Ypma (1981) were 3.29 (± 0.49, n=8) after 3 weeks, 3.80 (± 0.45, n=5) after 6 weeks, 3.40 (± 0.89, n=5) after 12 weeks, 2.33 (± 0.58, n=3)

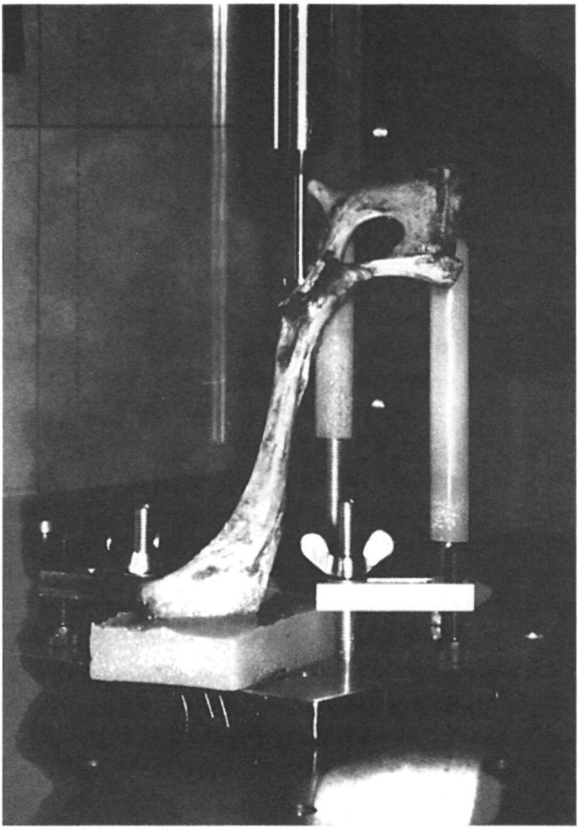

Figure 4.5b. *Detail of the pelvis half during loading test*

after 24 weeks and 1.33 (± 0.58, n=3) after 48 weeks respectively. The details of the clinical scores are summarized in table 4.1. Excluded from this observation were the goats with infection or dislocation. The clinical score up to 12 weeks was generally good, but a diminished weight-bearing pattern was recorded at 24 and 48 weeks (fig. 4.8a). Figure 4.8b represents the cup fixation at sacrifice.

On the radiographs of the specimens, consolidation and incorporation of the graft were assessed, together with the appearance of the graft-cement interface (fig. 4.4 a,b,c,d). Goat 88B showed no signs of graft consolidation and incorporation at 12 weeks, in the presence of infection. The two other animals at 12 weeks showed complete incorporation, without radiolucency at the cement-graft interface. At 48 weeks all three goats showed complete radiolucency at the graft-cement interface as signs of cup instability, with resorption of large parts of the graft. The details of the radiographic score are summarized in table 4.2.

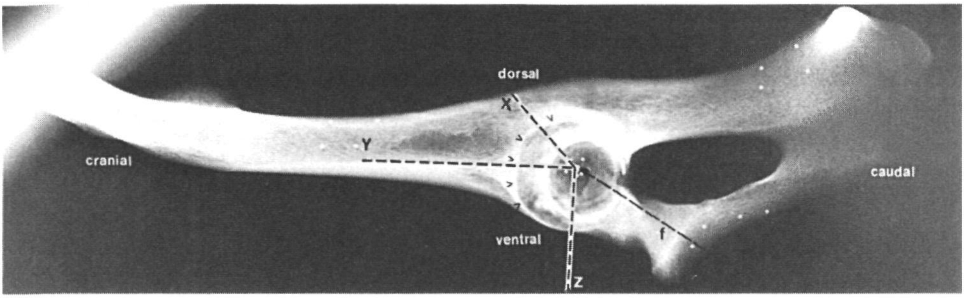

Figure 4.6a. *Radiograph of the left pelvis of the goat in standing position. Tantalum ball clusters at three positions in the bone. Laboratory coordinate system is shown with the origin determined by the four tantalum balls inserted at the top of the cup. Load applied (f) is indicated 30 degrees relative to Y-axis (cranio-caudal) and 30 degrees relative to X-axis (medial-lateral). Arrowheads are pointing to the graft.*

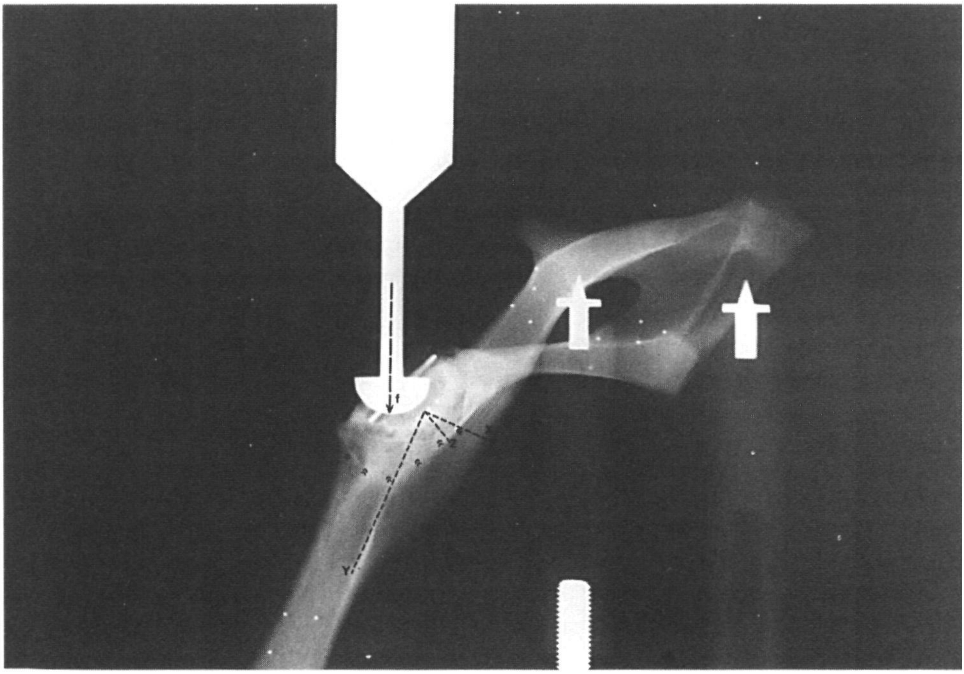

Figure 4.6b. *Radiograph of same left pelvis as in fig. 4.5b mounted in MTS machine during load application. Laboratory coordinate system is shown. Arrowheads are pointing to the graft.*

Table 4.2. *Radiographic score*

Goat number	Follow-up (weeks)	Consolidation	Incorporation	Graft/ cement interface
56LB	0	0	0	3
57LB	0	0	0	3
59LB	0	0	0	3
75B	3	0	0	3
69B	3	0	0	3
70B	3	0	0	3
81B	12	2	4	2
82B	12	2	4	2
88B	12	0	2	0
56RB	48	2	3	0
57RB	48	1	2	0
59RB	48	1	2	0

Consolidation

0 = non-union

1 = possible union. Passing trabeculae at <50% of graft-host junction.

2 = union. Passing trabeculae at 100% of graft-host junction.

Incorporation

0 = no resorption, no trabeculation

1 = fully resorbed graft

2 = >50% of graft resorbed

3 = <50% of graft resorbed with trabeculation in remaining graft.

4 = no resorption and complete trabeculation throughout graft.

Cement/graft interface

0 = complete radiolucency around cup.

1 = radiolucency around >50% of cup

2 = radioucency around <50% of cup

3 = no radiolucency

4.3.2 Mechanical testing

All test results are summarized in the Appendix, table 1

4.3.2.1 0 Weeks (goats 56LB, 57LB, 59LB)

Except specimen 57LB, all specimens showed elastic recovery after unloading. In specimen 57LB the motion and elastic recovery after unloading could not be measured due to technical problems during testing at the moment after unloading, therefore only migration 10 minutes after 700N loading was recorded. Most translation occurred along the cranio-caudal Y-axis (fig. 4.9). The maximum permanent (non-elastic) translation found was 0.572 mm (specimen 59LB). Permanent (non-elastic) rotations were largest around the medial-lateral (X) axis with a maximum of -2.970 degrees in goat 59LB (fig. 4.10).

4.3.2.2 3 Weeks (goats 69B, 70B, 75B)

Elastic recovery after unloading was observed during most tests, although this phenomenon was far less marked in rotations compared to the translations. Permanent (non-elastic) translations were largest along the dorso-ventral Z-axis with a maximum of -0.375 mm for goat 70B (fig. 4.9). Specimen 69B showed rather excessive permanent (non-elastic) rotations along all 3 axes with less elastic recovery, compared to the other specimens (fig. 4.10). In contrast, permanent translation pattern and elastic recovery in this specimen, did not differ significantly from the other two tested specimens (fig. 4.9). Also, clinically, radiographically and by manual testing loosening of this specimen was not suspected (table 4.1 and 4.2).

4.3.2.3 12 Weeks (goats 81B, 82B, 88B)

As could be expected from findings at harvest, goat 88B showed relatively large motions in all directions (figs. 4.9, 4.10 and 4.11). Our test results confirmed the loosening of this infected specimen. Permanent translations for specimens 81B and 82B were clearly less compared to the goats tested at 0 and 3 weeks, with a maximum of -0.161 mm along the dorso-ventral (Z) axis (specimen 82B) (fig. 4.9). Maximum permanent rotation was recorded in specimen 82B: -2.03 degrees around the dorso-ventral Z-axis, whereas permanent rotation around X- and Y-axis were -0.180 and 0.460 degrees respectively (fig. 4.10).

4.3.2.4 48 weeks (goat 56R)

Only one specimen could be tested, because the other two specimens showed complete cup loosening and graft resorption at sacrifice. Maximum permanent translation of 0.509 mm was measured along the cranio-caudal Y-axis (fig. 4.9). Maximum permanent rotation was 1.660 degrees around the dorso-ventral Z-axis (fig. 4.10).

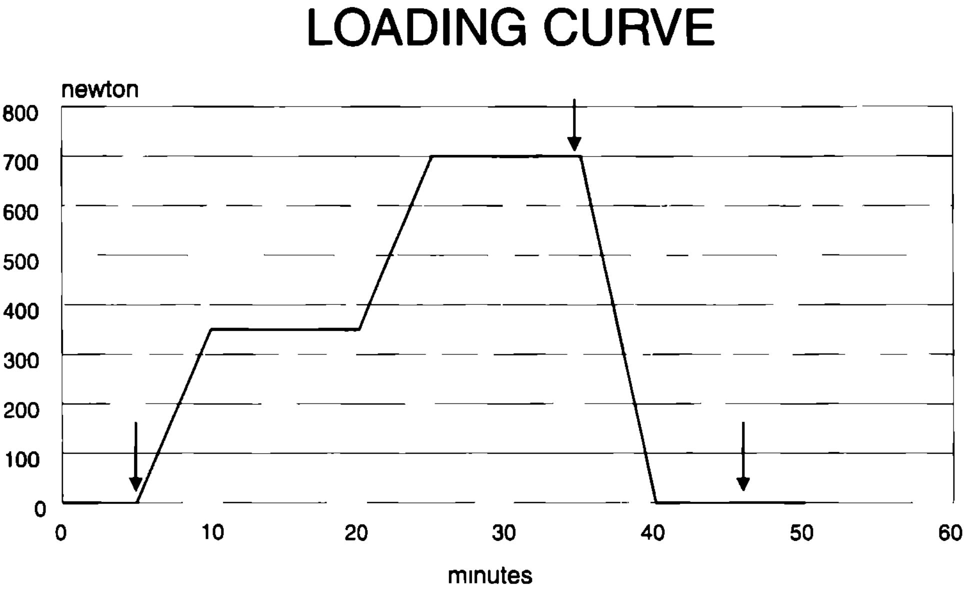

Figure 4.7. *Loading curve Arrows indicate moments when stereo-roentgenograms were taken*

4.4 Discussion

Successful total hip reconstruction augmented with bone grafts, requires sufficient initial stability of the implants to enable the bone graft to incorporate This has, for example, been illustrated by bone graft resorption in the presence of a bipolar hip arthroplasty with a mobile cup (Wilson et al 1989, Brien et al 1990) Schreurs et al (1994) demonstrated incorporation of morsellized cancellous allografts in the femur with a cemented femoral component in an animal model with goats In that study increasing implant stability was observed during the incorporation process It is difficult to define exactly implant stability All implants, even when clinically asymptomatic and considered stable, migrate to a certain extent (Baldursson et al 1980) They studied in-vivo migration of asymptomatic cemented acetabular sockets with RSA After 2 years, cranial migration up to 1 8 mm and variable rotations around three axes up to 5 5 degrees were found

To assess initial cup stability in this study, 3 goats were operated in-vivo and sacrificed immediately after the operation It was considered important to perform the procedure in-vivo, because cementing quality might differ from post-mortem laboratory conditions without blood interposition

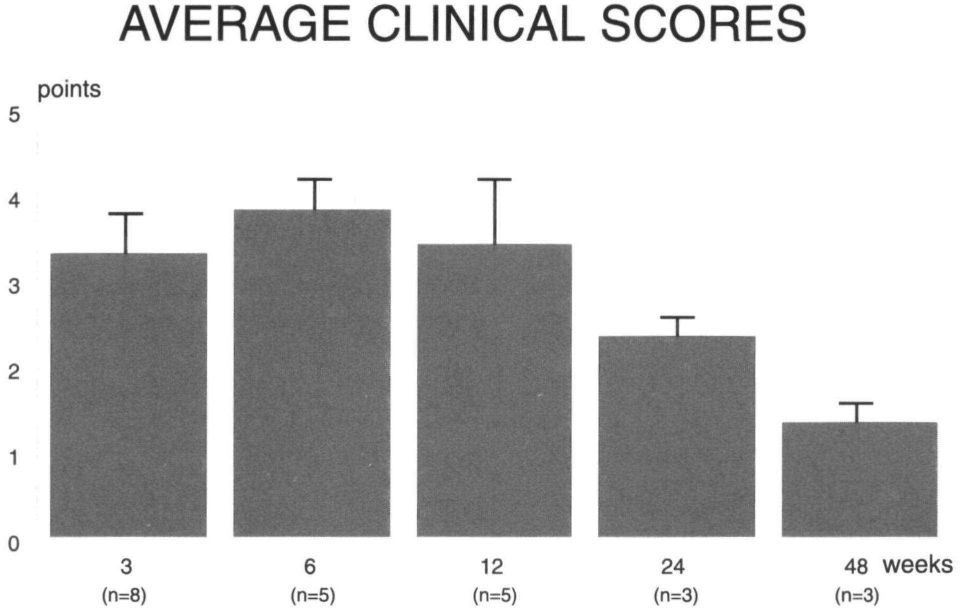

Figure 4.8a. *Average clinical score at several time points according to Ypma (1981)*

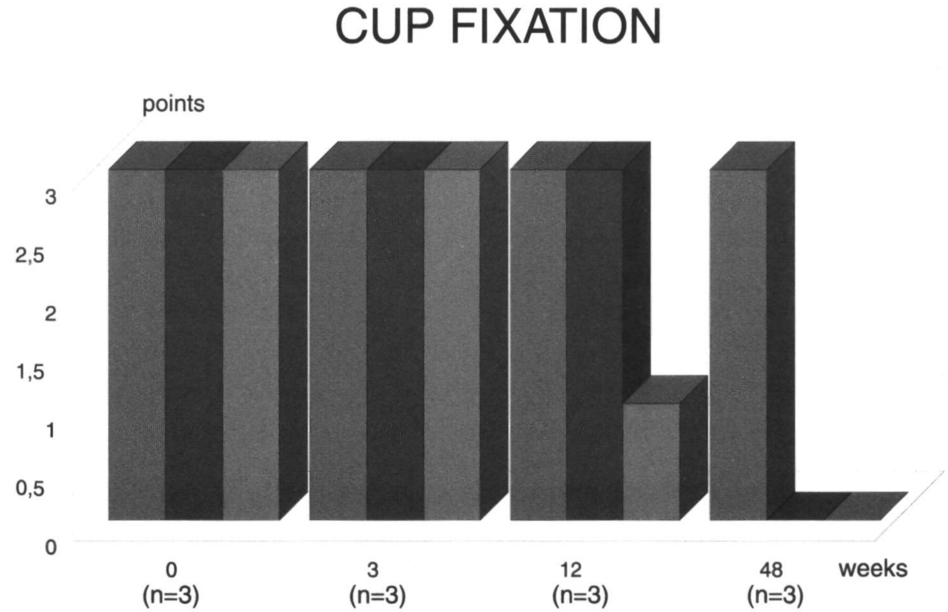

Figure 4.8b. *Cup fixation at sacrifice, scored according to Ypma (1981)*

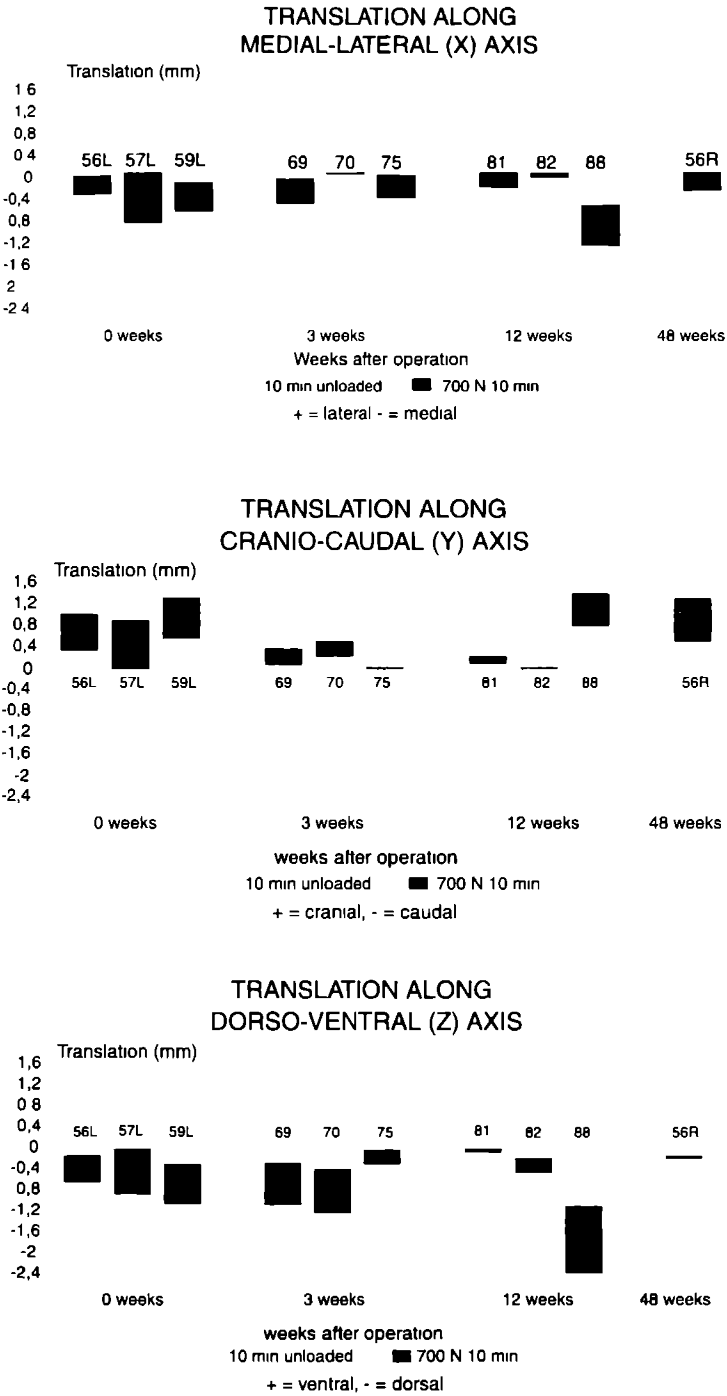

Figure 4.9. *Translations found in all three directions along the axes of the coordinate system immediately after implantation and at 3, 12 and 48 weeks after implantation after 10 minutes 700N loading and 10 minutes after unloading. Goat 88R showed excessive translations and loosening had been confirmed at harvest*

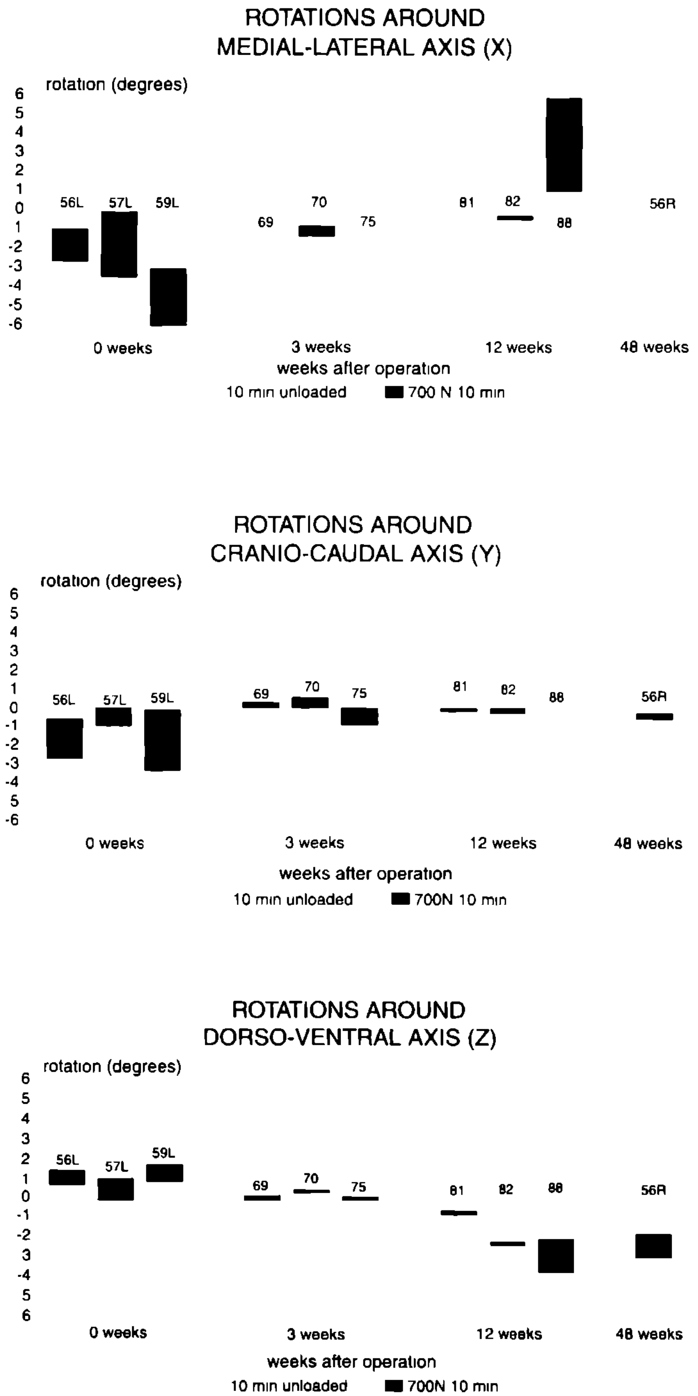

Figure 4.10.
Rotations around all three axes of the coordinate system immediately after implantation and at 3, 12 and 48 weeks after implantation after 10 minutes 700N loading and 10 minutes after unloading. Goat 88R showed excessive rotations and loosening had been confirmed at harvest.

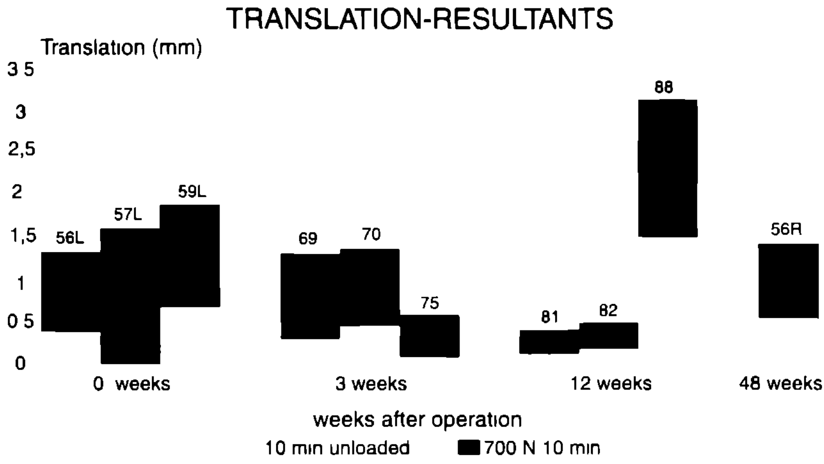

Figure 4.11. *Resultant of translations*

Although cup stability, at the several time points, varied considerably in our study, and the number of animals was small, some trends during the first twelve weeks could be observed in accordance with the clinical and radiographic results From 0 to 12 weeks, translations had gradually decreased, excluded the infected specimen For rotations the results were less clear, but more or less the same trend was present During the interval 0 to 12 weeks, radiographic signs of graft incorporation became apparent Trabeculae crossing the graft host junction and development of a trabecular pattern in the graft after 12 weeks, were considered radiographic signs of consolidation and incorporation Also the clinical performance of most of the animals up to 12 weeks might suggest a stable implant The results after 48 weeks must be considered as poor Two cups had completely loosened and dislocated at sacrifice with graft resorption The only cup tested after 48 weeks (goat 56RB) was clinically stable at sacrifice A thick radiolucent interface at the cement-graft junction with partial graft resorption was present Loading test showed maximum motions in the same range as at the direct post-operative situation, but significantly more motion compared to the specimens tested at 12 weeks

Apart from biological processes, differences between 0 and 3 weeks might be explained by different modes of graft impaction and cementing It is supposed that mode of impaction and cementing quality influence initial stability to a large extent, although this could not be proved specifically by this study Especially goat 69B (3 weeks) showed relatively large rotations, although translations were rather small, and the cup was well fixed at sacrifice with no radiographic signs of loosening

Differences in direction of cup migration (negative or positive values), which were especially present in rotations, might probably be explained by different orientations of the socket in the acetabulum after insertion

Roentgen-stereophotogrammetric analysis (RSA) has proven to be a very useful and accurate tool in assessing implant migration, both in-vitro and in-vivo (Mjoeberg et al. 1984, Mjoeberg et al. 1987). Its accuracy is estimated 0.2 degrees for rotations and 0 1 mm for translations (Olsson et al. 1976). Comparing the accuracy of RSA and the acquired motion values in this study, the results can be considered significant, especially concerning rotation values.

4.5 Conclusion

Acetabular cups, augmented with impacted morsellized cancellous allograft bone, show increasing stability up to 12 weeks with radiographic signs of graft incorporation. After 48 weeks two out of three specimens showed at harvest total loosening of the cup with resorption of the graft. The only remaining specimen tested after 48 weeks showed (partial) resorption of the incorporated graft with maximum cup motion comparable to the direct post-operative situation

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CHAPTER 5

Acetabular reconstruction with impacted morsellized cancellous bone grafts in cemented revision hip arthroplasty: a radiologic study in 80 patients

5.1 Introduction

Increasing experience is gained world wide in revising loose total hip arthroplasties (THA). The causes for success or failure are better understood, but far from solved. The most challenging part of the procedure is how to deal with bone-stock loss, always accompanying a loosened component to a more or lesser degree (fig. 5.1). Several treatment modalities were proposed: large amounts of cement (Johnston 1986) (fig. 5.2), metal reinforcement devices (Schatzker et al. 1984) (fig. 5.3), custom made prostheses (Scales and Wright 1983), massive cortico-cancellous allografts (Oakeshott et al. 1987) or cancellous bone chips (McCollum et al. 1980). In the literature there is a trend towards biological reconstructions with bone grafts.

This study analyses retrospectively the radiographic results following revision surgery with an acetabular reconstruction technique using only impacted cancellous bone grafts combined with a cemented polyethylene cup.

5.2 Materials and methods

5.2.1 The series

Between january 1979 and january 1988 ninety-one cemented revision hip arthroplasties (83 patients) were performed at the Orthopaedic Department, University Hospital Nijmegen, combined with an acetabular reconstruction technique with impacted morsellized cancellous bone grafts.

In the first half of 1990, all patients were invited for a radiographic examination. Seven patients (7 hips) had died of causes not related to the revision procedure. One patient (1 hip) was lost to follow-up. As most patients were followed routinely at yearly intervals, it was possible to study the records and radiographs of their last visit. Five deceased patients with five hips and a minimum follow-up of 2 years could be included in the study using their most recent radiographs. Eight patients had undergone bilateral acetabular reconstructions. Of these, only the hip with the longest follow-up period was included in the study. From a statistical point of view it was considered incorrect to include both hips of a bilateral procedure in the study. Only independent observations can be used for statistical tests.

In total eighty hips in 80 patients with a minimum follow-up of 2.0 years and a maximum of 10.9 years (average 5.7 years) were included (fig. 5.4). This group consisted of 58 women

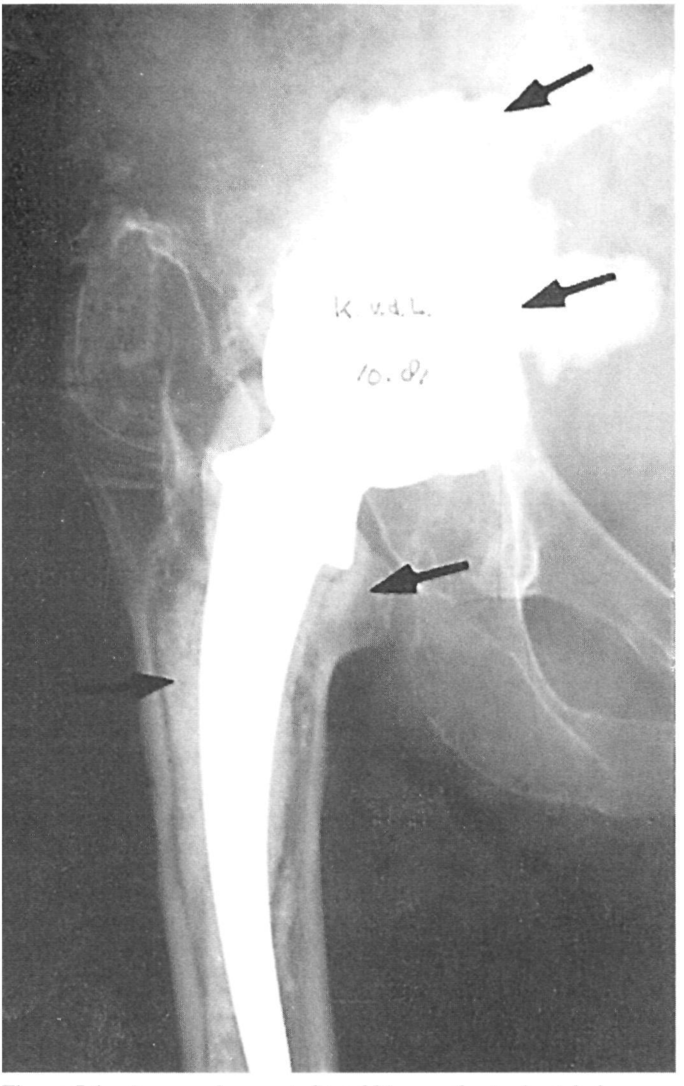


Figure 5.1. *Loosened cemented total hip prosthesis. Acetabular cup migration in superior and medial direction with severe bone stock loss. The femoral component has subsided with endosteal bone lysis.*

and 22 men with an average age at revision of 58 years (range 23-81 years). The diagnoses for which primary hip arthroplasty was performed are listed in table 5.1. In order to avoid creating too many small subgroups, three main primary diagnosis groups were considered: primary idiopatic coxarthritis, secondary coxarthritis (dysplasia, femoral head necrosis,

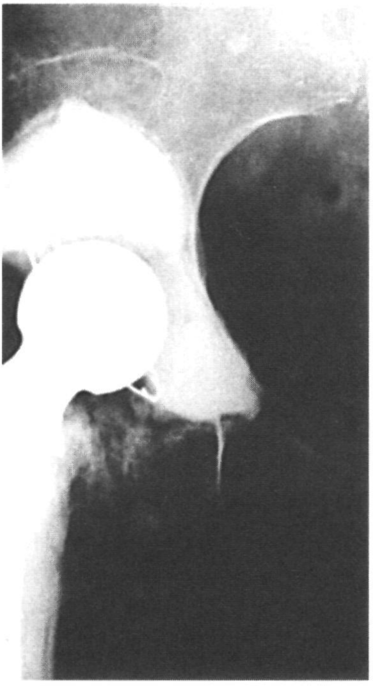


Figure 5.2. *Severe actebular bonestock deficiency completely filled with bone cement*

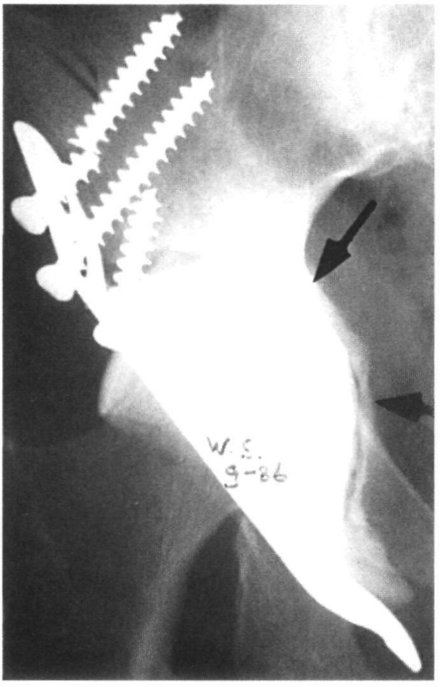


Figure 5.3. *Deficient actabulum with a metallic support ring containing a socket*

posttraumatic) and rheumatoid arthritis. Reasons for revision included 72 aseptic loosenings and 8 infected hips, documented with positive cultures.

Although all patients had a minimum follow-up of about 2 years, due to the large follow-up variation the individual results of the hip arthroplasties were not quite comparable. However there was some evidence that no serious confounding occurred in examining the influence on acetabular loosening and graft consolidation. Observing the six subgroups of primary diagnosis and acetabular defect combinations (table 5.2 and section 5.2.5), on the average the follow-up time only varied from 5.2 years to 6.8 years.

5.2.2 Surgical technique

The postero-lateral approach according to Gibson, modified by Kocher, was used in all cases (fig. 5.5a). Osteotomy of the greater trochanter was performed in 9 cases. Before capsular incision, joint fluid was aspirated for culture. A circumferential capsulotomy was performed. After removing the components, cement and interface fibrous tissue, a frozen section was taken from the interface tissue for determinig infection. More than 50 granulocytes per vi-

Table 5.1. *Some demographic and other characteristics of the 80 patients*

Age	mean = 58 years
	range = 23 - 81 years
	Number of patients
Sex	
– men	22
– women	58
Etiology	
– prim. osteoarthritis	49
– sec. osteoarthritis	22
– rheumatoid arthritis	9
Previous surgery	
– femoral head prosthesis	5
– double cup arthroplasty	12
– primary total hip	55
– one or more revisions	8

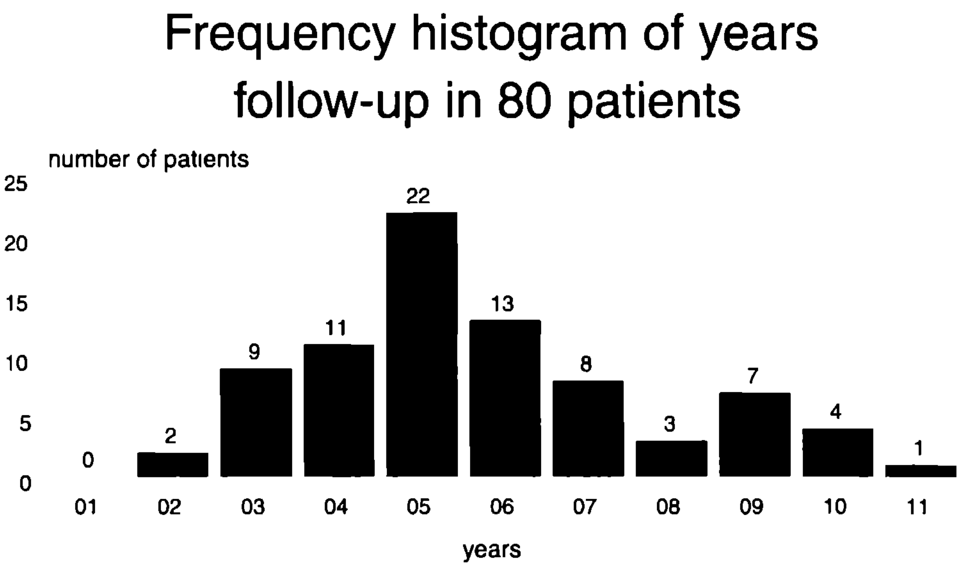


Figure 5.4. *Frequency distribution of follow up time of the 80 patients in the present study*

sion field was considered suspect for infection (Mirra et al 1976) The procedure was stopped in that case for infection treatment with gentamycin beads and systemic antibiotics The new components were placed at a later time

In preparing the acetabulum great care was taken to remove no more bone than absolutely necessary (fig 5 5b) Reconstruction was preceeded by placing a trial socket at the level of the tranverse ligament, i e the anatomical position of the acetabulum (fig 5 5c) In this way an impression was obtained about the extents of defects and the amount of graft needed Segmental defects in the medial wall were closed with a cortico cancellous slice of bone After curetting and roughening the pre-existent bone bed the chips were placed in the acetabulum, moulded and firmly impacted using the successive socket trial prostheses (fig 5 5d) The last socket trial prosthesis was 2 mm oversized to create a sufficient thick cement mantle As much chips were placed in the acetabulum till the new socket had been located in agreement with the original center of rotation (fig 5 5e) The impacted graft was covered with a thin vitallium wire mesh (fig 5 5f) and the cup (36 Muller cups, 40 Allopro cups and 4 other type cups) was cemented in position with gentamycin palacos cement (fig 5 5g) In fig 5 5h a schematic representation of the reconstruction technique is shown

5 2 3 Preparation of bone grafts

In case of revising a double cup arthroplasty, bone grafts were taken from the resected femoral heads In the early period of the series, autografts were taken from the iliac crest Most of the grafts were deep frozen femoral head allografts from the bone bank Allografts were used in 65 hips Fifteen autografts were used in the remaining cases

Grafts were prepared with a rongeur during surgery (fig 5 6a) All soft tissues were removed Cancellous bone chips with a diameter varying between 0 5 and 1 centimeter were obtained (fig 5 6b) Only the cancellous part of the femoral heads was used

5 2 4 Postoperative care

Postoperative care included anticoagulation therapy with sintrom during 3 months, systemic antibiotics during 5 days postoperatively, passive motion exercises after 24 hours ambulation with partial weight-bearing after 6 weeks and full weight bearing at 3 months To prevent heterotopic ossification patients got Indocid (3 x 50 mg daily) during the first 5 days In case of proven infection, systemic antibiotics were administered during 6 weeks, dependent on the cultures

5 2.5 Classification of acetabular defects

Each defect was classified on the basis of the preoperative and immediate postoperative radiographs and the operation record The AAOS classification system was used (D'Antonio et al 1989) This classification system has two basic categories segmental and cavitary defects (table 2 1) A segmental defect is any complete loss of bone in the supporting hemispere

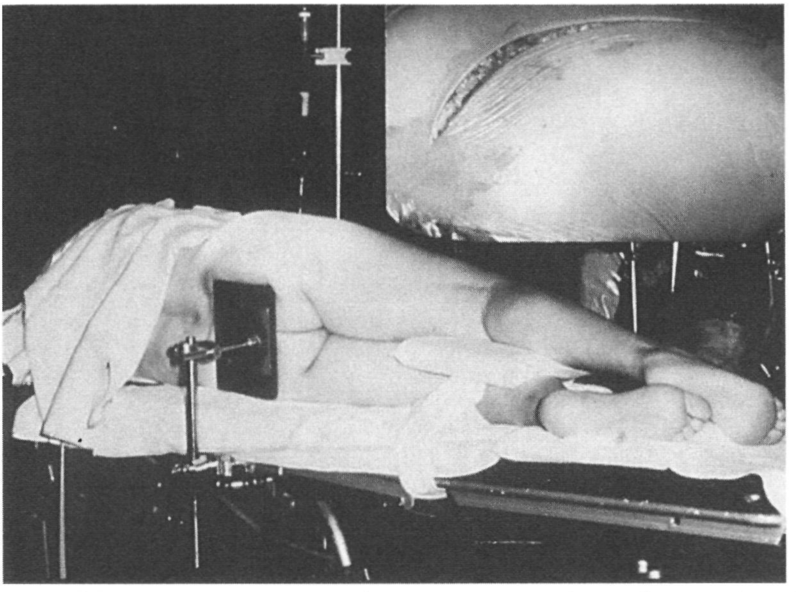


Figure 5.5a. *Positioning of patient during revision procedure with postero-lateral hip approach.*

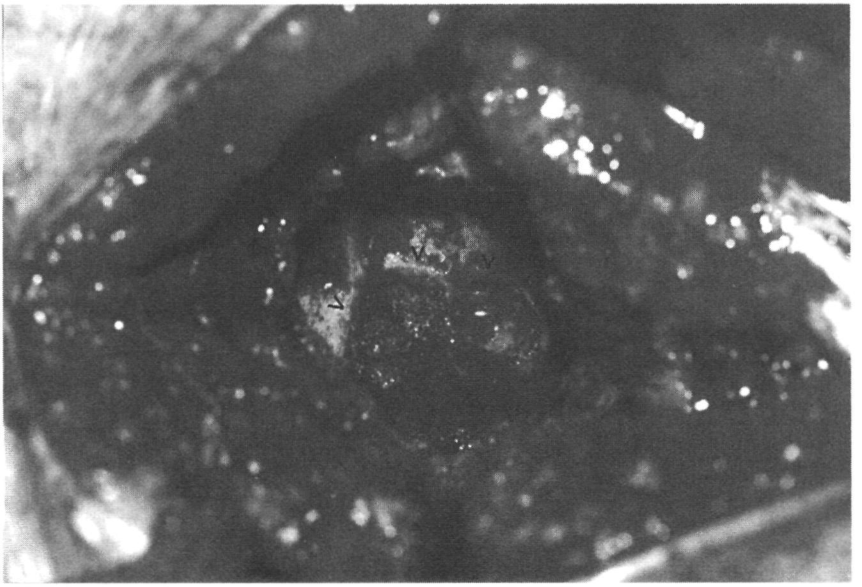


Figure 5.5b. *Acetabulum after removal of cup and cement showing segmental defects in the medial wall (arrowheads).*

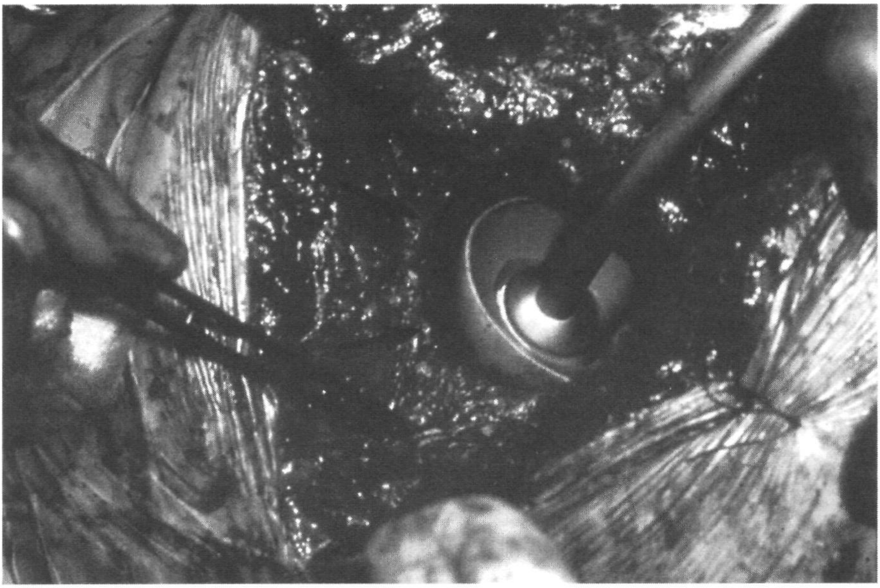


Figure 5.5c. *Socket trial-prosthesis placed in the deficient acetabulum. Arrows pointing to the superior cavitary defect with intact superior rim.*

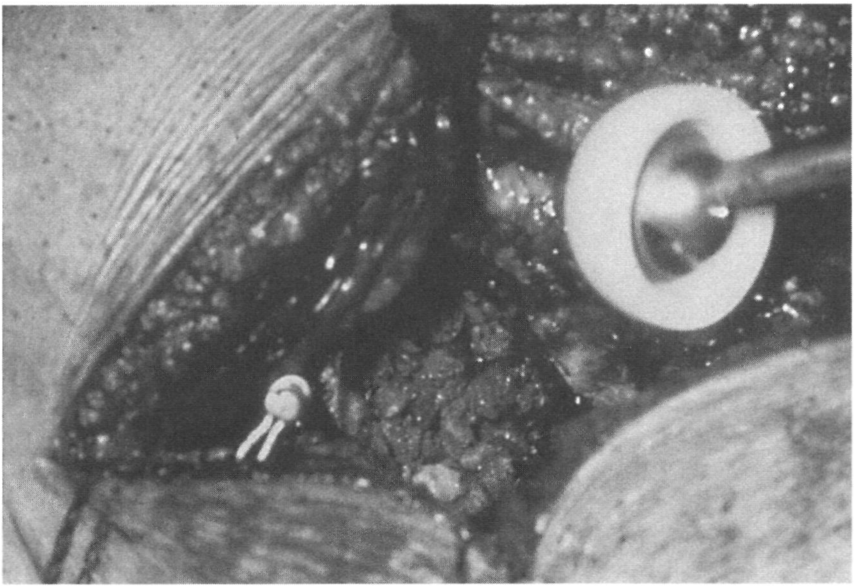


Figure 5.5d. *Prepared bone chips placed in the acetabulum with socket trial-prosthesis used as impactor.*

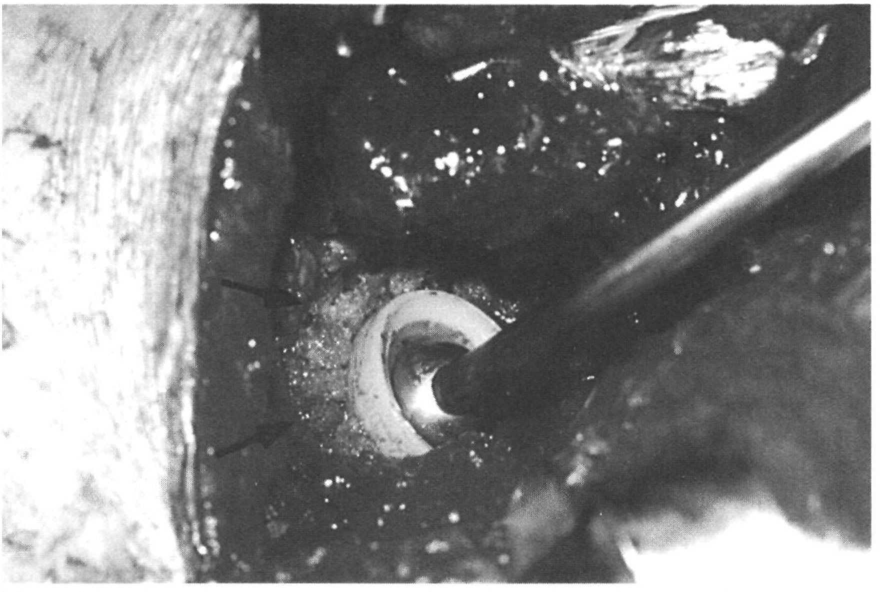


Figure 5.5e. *Bone chips after impaction. The socket trial-prosthesis is in the anatomical position.*

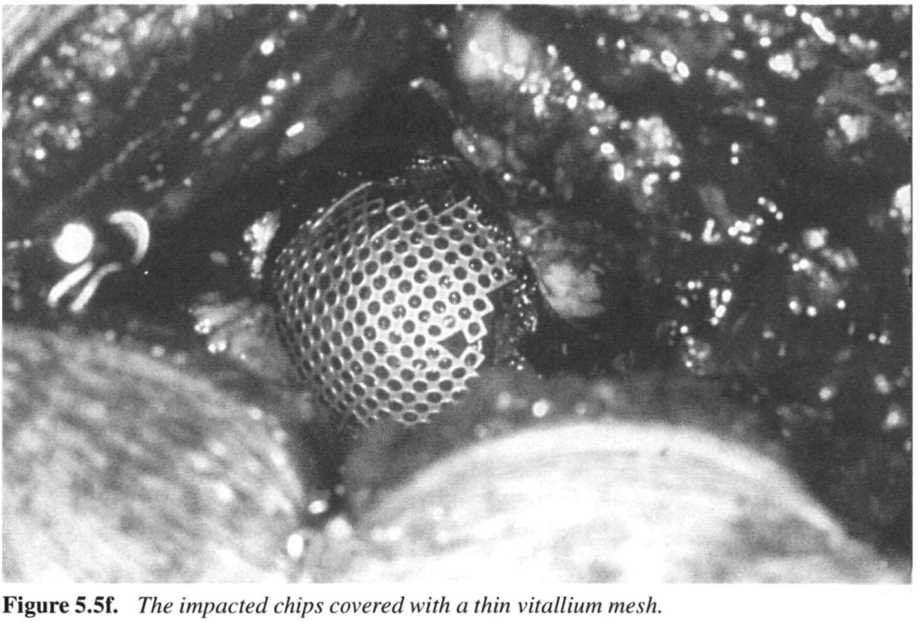


Figure 5.5f. *The impacted chips covered with a thin vitallium mesh.*

Figure 5.5g. *Cemented cup in the acetabulum reconstructed with impacted bone chips.*

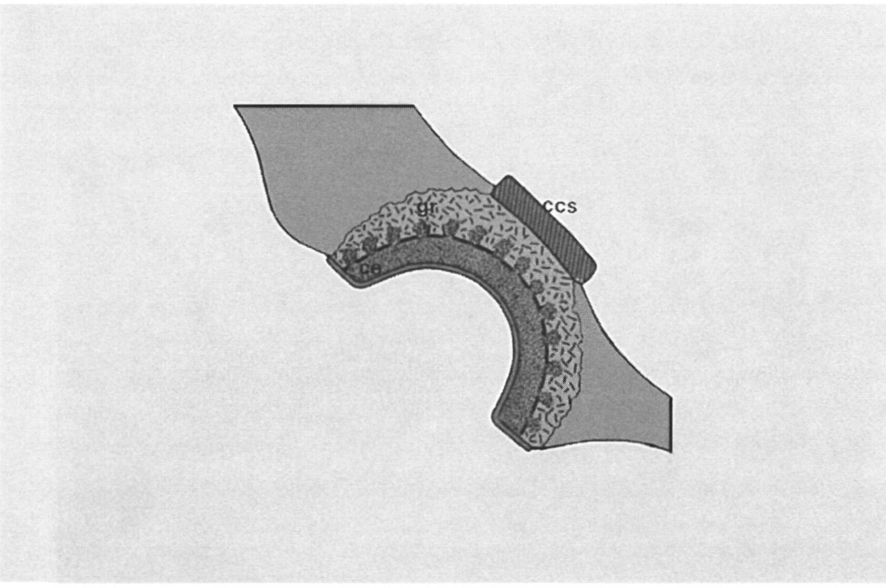


Figure 5.5h. *Schematic representation of the acetabulum reconstruction showing a cortico-cancellous shell (ccs) in a segmental medial wall defect, a layer of impacted bone chips (gr) and a cemented cup (ce).*

of the acetabulum, including the medial wall (fig. 2.2). Cavitary defects represent a volumetric bone loss of the acetabular cavity, including the medial wall, but the acetabular rim remains intact (fig. 2.1).

In order to avoid small subgroups, the defects were subdivided in two main categories: 42 cavitary and 38 combined segmental/cavitary defects. Table 5.2 shows the distribution of primary diagnoses for each main category. According to the chi-square test, there is no significant relation between primary diagnosis and defect (p=0.87).

Table 5.2. *Mean follow-up time in years (with standard deviations) for each of the six subgroups of primary diagnosis and acetabular defect combinations*

Type defect	Primary arthritis	Secondary arthritis	Rheumatoid arthritis	Total
Cavitary	N=26 (62%)	N=12 (29%)	N=4 (10%)	42
	5.4(±1.8)	5.9(±1.9)	6.8(±3.3)	
Segmental/	N=23 (61%)	N=10 (26%)	N=5 (13%)	38
cavitary	5.8(±2.3)	5.3(±2.2)	5.7(±2.1)	
Total	49	22	9	80

5.2.6 Radiographic evaluation

The anterior-posterior radiographs of the 80 hips were reviewed. Routine postoperative follow-up included visits with radiographs at 3 months, 6 months and 1 year, and thereafter at yearly intervals. Immediate postoperative and follow-up radiographs at 6 months, 1 year, at about 3 years and at the last follow-up visit were studied. The radiographs were assessed by the author.

5.2.6.1 Consolidation

Consolidation of the graft was defined as the presence of clearly delineated trabeculae bridging the host-graft junction (Conn et al. 1985).

5.2.6.2 Incorporation

Graft incorporation was defined as equal radiodensity of graft and host bone, with a continuous trabecular pattern throughout (Conn et al. 1985).

In practice it was impossible in most cases to establish the difference between consolidation and incorporation on radiographs (figs. 5.7 and 5.8). Especially when smaller amounts of grafts were used, well penetrated with bone cement, graft radiodensity and trabecular pattern throughout the graft could not reliably be assessed. Bridging trabeculae at the graft host junction appeared to be the only radiographic parameter which allowed reliable assessment. It was therefore decided to observe only graft consolidation. When there were no signs of full graft consolidation at 1 year postoperatively, subsequent radiographs were studied untill

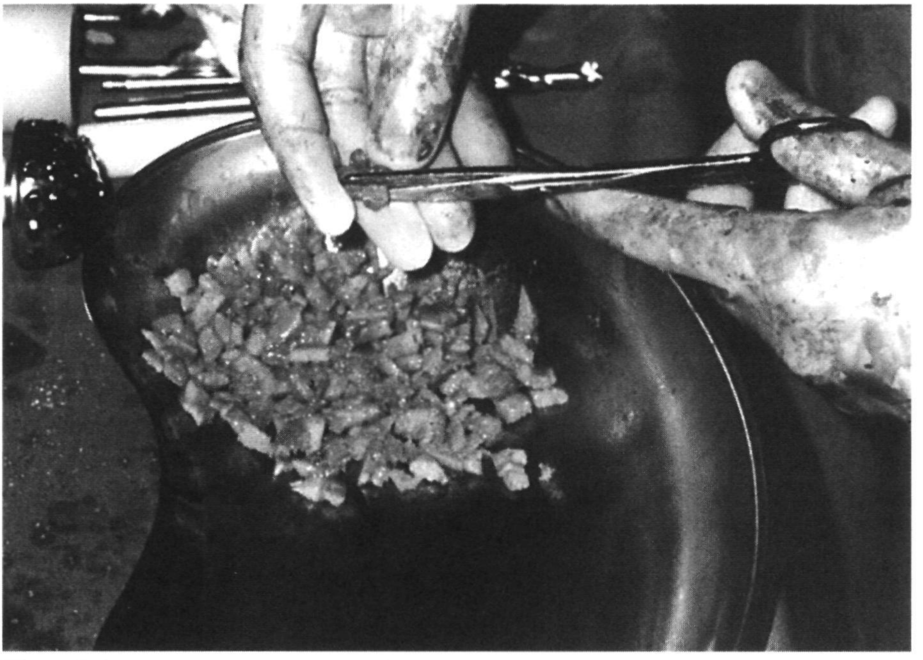


Figure 5.6a. *Preparation of bone grafts. Bone chips from the cancellous part of the femoral heads were prepared with a rongeur during surgery.*

consolidation was observed. As the exact moment of full graft consolidation could not be established, only the time interval in which this event occurred was known (interval-censored and right-censored data). Because the midpoints of the time intervals were distributed more or less lognormally this was also assumed for the times themselves. In order to study the influence of diagnosis and type of defect on the consolidation time, a survival analysis was applied, using the SAS PROCEDURE LIFEREG (1990), by assuming a two-way additive factorial model with respect to the expected values of the logarithmic transformed times. Analogously a separate one-way and a simple regression model have been applied for examining the influence of graft type respectively graft amount.

5.2.6.3 Radiolucency cement-graft interface

On all selected radiographs radiolucency at the bone-cement interface was assessed in three zones, according to DeLee and Charnley (1976). Radiolucency was considered present if the radiolucent line measured at least 2 mm in width.

5.2.6.4 Cup migration

Prosthesis migration in THA is generally considered a sign of loosening. Several problems in migration measurements on plain radiographs are encountered: variable magnification of the

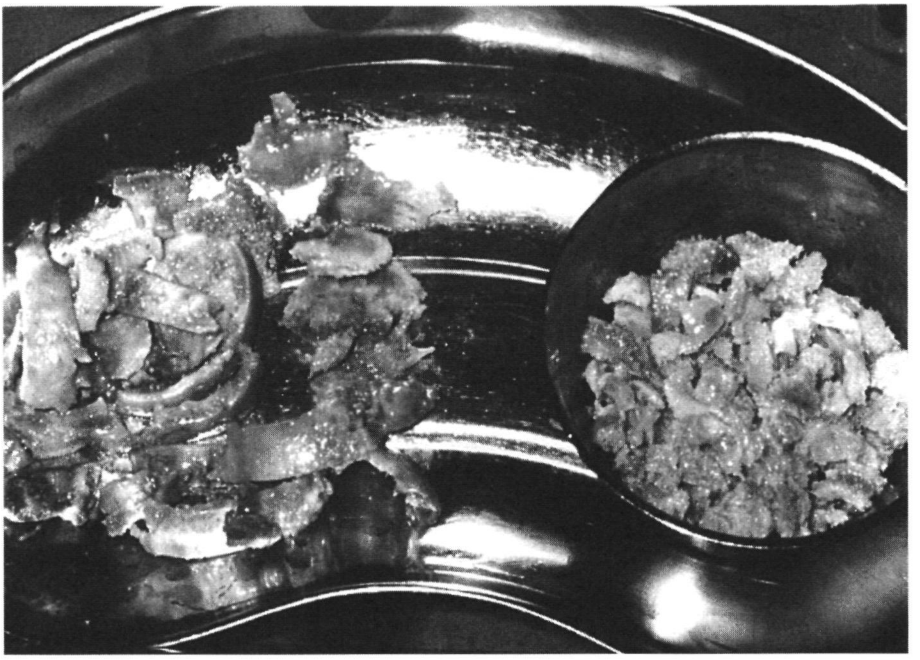


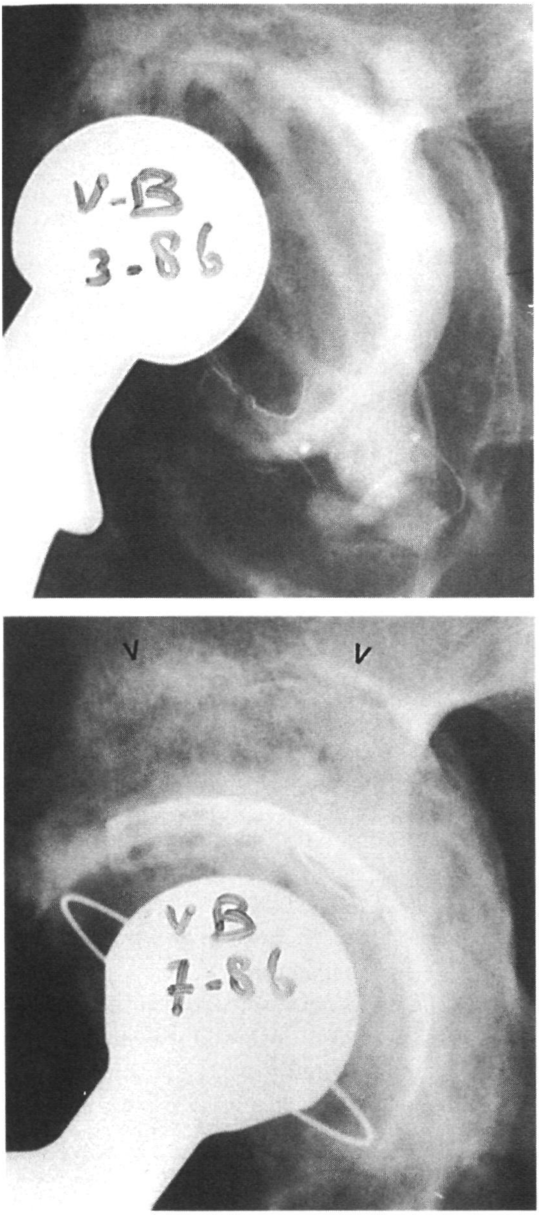
Figure 5.6b. *Bone chips with a diameter varying between 1/2 and 1 centimeter were obtained. On the left the remaining cortico-cancellous shells which were used for closing segmental medial wall defects.*

radiographic image, differences in radiographic projection, insufficient reproducible prosthesis- and skeletal landmarks, different positions of the patient.

Several methods for migration measurement were developed (Mjoberg et al. 1985, Ilchmann et al. 1992, Sutherland et al. 1982, Callaghan et al. 1979, Harris et al. 1982). Most of them did not fully solve the problems mentioned. An additional problem in this series was, besides not-standardized AP-pelvis radiographs, the presence of some hip-centered radiographs in the early years of this series. Twenty five percent of reviewed radiographs were hip-centered, the remaining were AP-pelvis radiographs. Therefore we had to adjust for differences between these types of radiographs to obtain comparable migration measurements (see section 5.2.6.6).

Radiographs were digitized (TEA Image Manager System, DIFA Measuring Systems B.V., Breda, The Netherlands) and a computer program was developed, which made it possible to perform reproducible measurements on a monitor. In each radiograph magnification factor was determined based on the known 32 mm diameter femoral head used in all patients.

A coordinate system was applied in each radiograph (fig. 5.9). The Köhler line (K) was chosen as Y-axis (the line along the medial aspect of ilium and ischium). The line T running



A

B

Figure 5.7. *A. Severely deficient acetabulum with migrated cemented cup. Type defect is superior segmental, medial/superior cavitary. B. Immediately after reconstruction with morsellized cancellous allografts and a cemented cup. Arrowheads pointing to the clearly visible graft-host junction.*

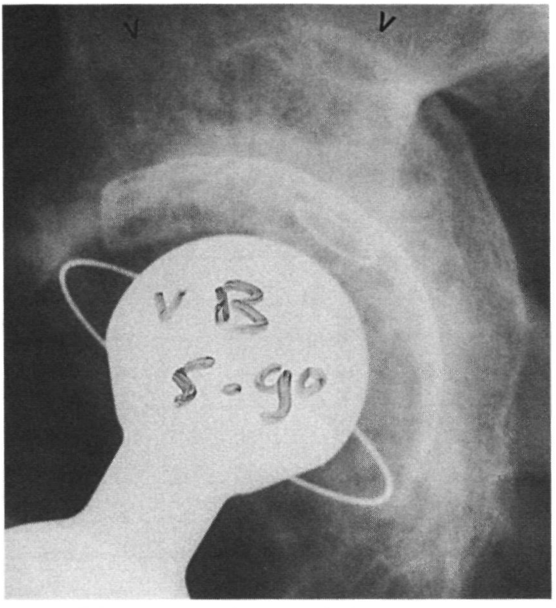
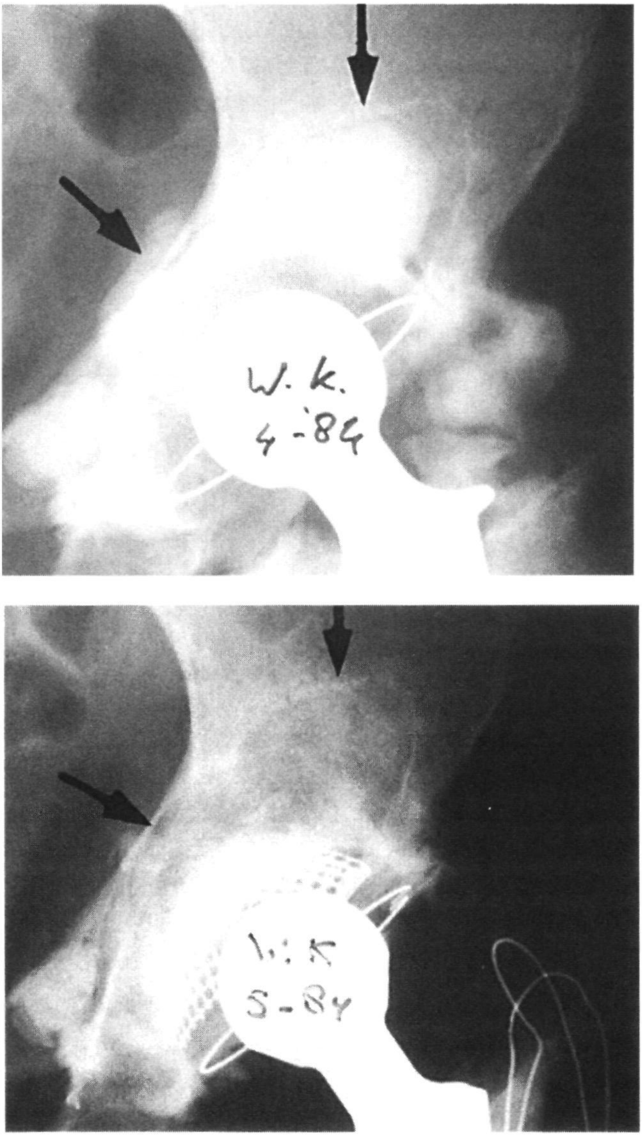

C

Figure 5.7. *(Continued) C. Nearly four years after reconstruction. Consolidation is present; clearly delineated trabeculae are bridging the graft-host junction (arrowheads). Incorporation is more difficult to assess; a continuous trabecular pattern throughout the graft cannot fully be observed,as is the case for the appearance of radiodensity. Without doubt the graft has incorporated otherwise graft collapse would have occurred in the course of time.*

perpendicular to the line K and tangential to the inferior aspect of the teardrop was chosen as X-axis. As reference point on the acetabular cup, the center of the projected elliptical image of the metallic ring at the periphery of the cup was chosen. This point C, considered as the center of the cup, was determined by bisecting the long axis a-b of the projected ellipse. The angle between the long axis of the ellipse and the line T was defined inclination angle and was measured in each radiograph.

5.2.6.5 Graft amount

To get an impression about the amount of graft used, on each immediate postoperative radiograph two additional measurements were made (fig. 5.9). A line from C perpendicular to line K was drawn and the distance between the points e1-e2 on this line gave a global impression about the graft amount in the medial direction. Perpendicular to this line, 1 cm medial from C, another line was drawn on which the distance between the points e3-e4 gave a global impression of the graft amount in the superior direction. The total graft amount was simply considered the sum of these two distances e1-e2 and e3-e4. It must be stressed that this is only a very rough estimate of the amount of graft used in the reconstruction.



A

B

Figure 5.8. *A. Loosened cup with large amount of bone cement and considerable osteolysis. Type defect is medial segmental, medial/superior cavitary. B. Immediately after reconstruction with a cortico-cancellous shell in the medial wall defect and morsellized cancellous allografts to repair the cavitary defects. Graft-host junction is clearly visible (arrows).*

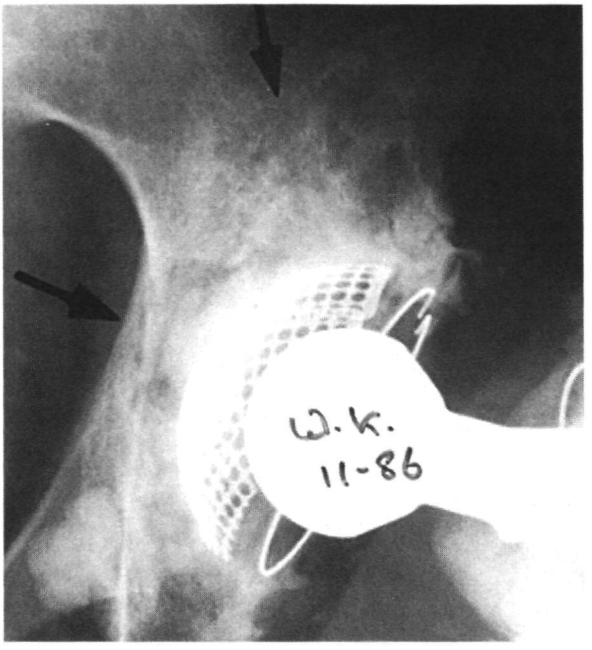


Figure 5.8. *(Continued) C. Two and a halve year after reconstruction. Graft-host junction can not be distinguished anymore as sign of full consolidation. A trabecular pattern throughout the graft is difficult to assess, as is the case for comparing radiodensity of graft and host bone.*

5.2.6.6 Comparative study of cup migration in hip-centered and symphysis-centered anterior-posterior (AP)-pelvis radiographs

To determine how to deal with different types of radiographs (hip-centered and AP-pelvis) for measuring migration, a comparative study was performed. From ten patients both hip-centered and AP-pelvis symphysis-centerd radiographs were taken at the same time and measured five times according the described technique. Comparisons were made with respect to the inclination angle and the distance of cup center C to X-axis and Y-axis. It appeared that the mean values for distance of cup center C to X-axis and Y-axis were systematically about 1 mm larger on the AP-pelvis radiographs compared to the hip-centered radiographs. Standard deviation of measurement errors was about 0.4 mm. Generally, in the complete study of the 80 patients, every distance was based on 3 repeated measurements, which means that probably the total maximum error of measurement amounts to about
$2/\sqrt{3}x0,4mm=0,5mm$.

According to Sutherland et al. (1982) total error in recording reference points is about 0.5 mm and errors due to differences in pelvis rotation about 1.5 mm. Therefore total maximum error per distance is about 2.5 mm. So in case of some type of radiograph, migration was

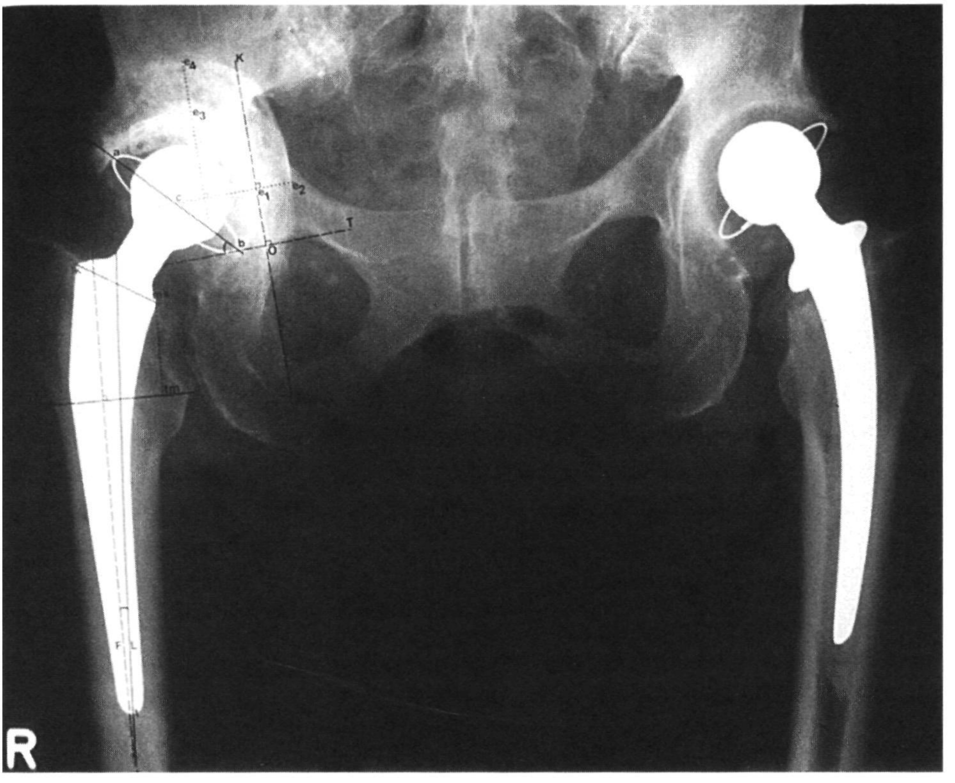


Figure 5.9. *Anterior-posterior pelvis radiograph. The right acetabulum is reconstructed with morsellized bone grafts. Around the acetabulum a coordinate system is shown allowing migration measurements. Line K (Y-axis): Kohler line along medial aspect of ichial and iliac bone. Line T (X-axis): perpendicular to line K and tangential to inferior aspect of teardrop. Line a-b: long axis of projected wire marker. Point c: Cup center halfway a-b. e1-e2: graft amount in medial direction. e3-e4: graft amount in superior direction.*

defined as a difference of more than 5 mm between two radiographs. Because errors can compensate each other, migration could not fully be excluded at lesser differences. In case of different types of radiographs, migration was assumed if the difference AP-pelvis distance at one time minus hip-centered distance at the other time was larger than 6 mm or smaller than -4 mm.

Unfortunately no total error of cup inclination angle measurement was known. Therefore this parameter could not be included in this series.

5.2.6.7 Definition of failure and radiographic loosening

The acetabular component was considered failed if re-revision had taken place.

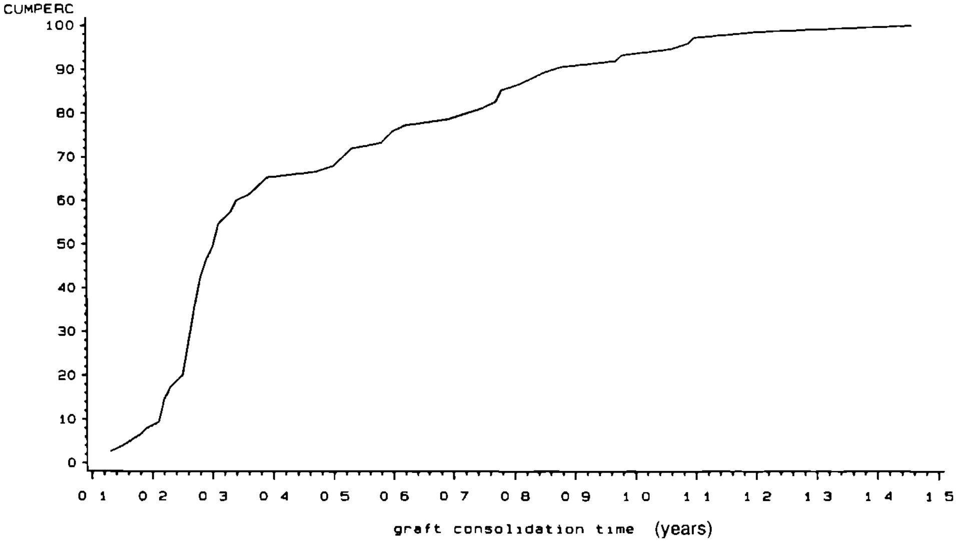


Figure 5.10. *Cumulative distribution of the midpoints of time intervals, during which graft consolidation occurred*

Radiographic loosening was considered present if one or both of the following criteria were met

- Migration > 5 mm in one or two directions after correction for radiograph type
- Radiolucency ≥ 2mm at the bone-cement interface in at least two of the three acetabular zones as defined by DeLee and Charnley (1976) simultaneously

5.3 Results

The observations of the 80 cups are restored in the Appendix, table 2

5.3.1 Re-revisions

Two acetabular cups had been re-revised during the follow-up period One case was due to a recurrent infection The data of these cases are listed in table 5 3

5.3.2 Graft consolidation

In 4 hips no graft consolidation had occurred (5%). All other reconstructions showed complete consolidation along the whole graft. The data of the cases with failed consolidation are listed in table 5.4.

Table 5.3. *Two cases with re-revision acetabular cup*

Type defect	Primary diagnosis	Reason revision	Graft amount (mm)	Type graft	Consolidation graft	Radiolucency (2 or 3 zones)	Clear migration
cavitary	secondary arthritis	infection	42	autograft	+		+
cavitary	primary arthritis	aseptic	32	allograft	+	+	+

Table 5.4. *Four cases with failed graft consolidation (the 2 re-revisions had full graft consolidation)*

Primary diagnosis	Graft amount (mm)	Type graft	Defect	Radiolucency (2 or 3 zones)	Clear migration
secondary arthritis	18	allograft	cavitary		
secondary arthritis	30	allograft	cavitary		+
secondary arthritis	29	allograft	cavitary	+	+
primary arthritis	6	autograft	combined	+	+

After excluding the two re-revised hips (both with full graft consolidation), three hips with allografts out of 64 (5%) and 1 hip with autograft out of 14 (7%) failed to consolidate. The probability of consolidation failure is not significant different with regard to type of graft (p=0.56, Fisher's exact test).

As regards the time of consolidation, figure 5.10 presents the cumulative distribution of the midpoints of the time intervals, during which consolidation occurred. Clearly, the distribution is skewed to the right. In table 5.5 estimates of consolidation times for the different defect diagnosis combinations are shown. Longest median consolidation time was found in patients with secondary arthritis and a combined defect (0.58 years), whereas this period was shortest in RA patients with a cavitary defect (0.19 years). According to the chi-square test of Wald there is no significant influence of defect type (p=0.21) and primary diagnosis (p=0.24) on the consolidation time.

Table 5.5. *Maximum likelihood estimates for the median (and 10th and 90th percentile) of the consolidation time distribution for the different diagnosis-defects combinations (including the 2 re-revisions) according to a survival analysis. Chi-square test of Wald. p=0.24 (diagnosis) and p=0.21 (defect)*

Diagnosis	Segmental/cavitary defect	Cavitary defect
Rheumatoid arthritis	0.27 yrs (0.07-1.13)	0.19 yrs (0.05-0.78)
Secondary arthritis	0.58 yrs (0.14-2.36)	0.40 yrs (0.10-1.64)
Primary arthritis	0.35 yrs (0.09-1.45)	0.24 yrs (0.06-1.00)

Table 5.6. *Maximum likelihood estimates for the median (and 10th and 90th percentile) of the consolidation time distribution for graft type (including the 2 re-revisions) according to a survival analysis. Chi-square test of Wald. p=0.39*

Graft type	Consolidation time
Allograft	0.30 yrs (0.07-1.31)
Autograft	0.42 yrs (0.10-1.83)

Table 5.7. *Maximum likelihood estimates for the median (and 10th and 90th percentile) of the consolidation time distribution for graft amount (including 2 re-revisions) according to a survival analysis. Chi-square test of Wald. p=0.01*

Graft amount	Consolidation time
3 mm (minimum)	0.16 yrs (0.04-0.65)
20 mm (mean)	0.32 yrs (0.08-1.30)
42 mm (maximum)	0.75 yrs (0.18-3.09)

Median consolidation time was 0.42 years for autografts and 0.30 years for allografts (table 5.6). This is not significant different (p=0.39, chi-square test of Wald).

Considering consolidation time with respect to graft amount, graft consolidation takes longer with increasing graft amount (p=0.01, chi-square test of Wald) (table 5.7).

5.3.3 Radiolucency

Radiolucency ≥ 2mm in one zone was observed in 12 hips. Radiolucency ≥ 2mm in at least 2 zones was encountered in 6 hips. Two times in 2 zones and four times in all 3 zones. The two hips that had been re-revised were excluded from this observation. Data are listed in table 5.8. The probability of radiolucency in at least 2 acetabular zones was 8% both for combined segmental/cavitary and cavitary defects (table 5.9).

Table 5.8. *Six cases with radiolucency ≥ 2mm at bone/cement interface in at least two zones (excluding 2 re-revisions)*

Defect	Primary diagnosis	Graft amount (mm)	Type graft	Consolidation	Clear migration
cavitary	secondary arthritis	17	autograft	+	-
combined	primary arthritis	21	autograft	+	-
cavitary	secondary arthritis	29	allograft	-	+
combined	primary arthritis	6	autograft	-	+
combined	rheumatoid arthritis	13	autograft	+	+
cavitary	rheumatoid arthritis	12	allograft	+	-

Table 5.9. *Frequency distribution of radiolucency (≥ 2mm in at least two acetabular zones) in different defect groups. (two re-revisions excluded). Fisher's exact test p=1.0.*

Type defect	Radiolucency 2 or 3 zones	No or 1-zone radiolucency	Total
Segmental/cavitary	3 (8%)	35 (92%)	38
Cavitary	3 (8%)	37 (93%)	40
Total	6	72	78

Table 5.10. *Frequency distribution of radiolucency (≥2mm in at least two acetabular zones) in different primary diagnosis groups (two re-revisions excluded). Chi-square test: p=0.22.*

Primary diagnosis	Radiolucency 2 or 3 zones	No or 1-zone radiolucency	Total
Rheumatoid arthritis	2 (22%)	7 (78%)	9
Secondary arthritis	1 (5%)	20 (95%)	21
Primary arthritis	3 (6%)	45 (94%)	48
Total	6	72	78

Table 5.11. *Frequency distribution of radiolucency (≥ 2 mm in at least 2 acetabular zones) for allografts and autografts (two re-revisions excluded). Fisher's exact test. p=0.008.*

Type graft	Radiolucency 2 or 3 zones	No or 1-zone radiolucency	Total
Allograft	2 (3%)	62 (97%)	64
Autograft	4 (29%)	10 (71%)	14
Total	6	72	78

The probability of radiolucency in at least 2 zones for different primary diagnoses was 6% in primary arthritis, 5% in secondary arthritis and 22% in rheumatoid arthritis (table 5 10) According to the chi-square test of homogeneity, there are no significant differences between the three primary diagnosis groups (p=0 22)

In four out of six radiolucent cases (2 or 3 zones) autografts were used, whereas the number of autografts in this series was far less, compared to the number of allografts The probability of radiolucency in two or three zones for autografts and allografts was respectively 29% and 3% (table 5 11) According to Fisher's exact test this is significantly different (p=0 008)

Fifty percent of reconstructions in which the bone graft had not consolidated, developed radiolucency in 2 or 3 zones In consolidated bone grafts this was 5% (table 5 12) According to Fisher's exact test this is a significant difference (p=0 03)

Table 5.12 *Frequency distribution of radiolucency (≥2 mm in 2 or 3 acetabular zones) in consolidated and non consolidated reconstructions (two re revisions excluded) Fisher s exact test p=0 03*

Consolidation	Radiolucency 2 or 3 zones	No or 1-zone radiolucency	Total
No	2 (50%)	2 (50%)	4
Full	4 (5%)	70 (95%)	74
Total	6	72	78

5.3.4 *Cup migration*

Two re-revised cups were excluded from observation

Radiograph-type corrected migration >5mm in vertical and/or horizontal direction between two observations was seen in 11 cases (table 5 13)

In 3 of these cases accompanying radiolucency ≥ 2mm in 2 or 3 zones was present Table 5 14 shows the frequency distribution of migration for radiolucency groups According to Fisher's exact test the probability of clear cup migration in the presence of 2- or 3-zone radiolucency (50%) is significantly larger compared to cases with no or 1-zone radiolucency (11%) (p=0 03)

In 3 cases with clear migration no graft consolidation was observed In table 5 15 the frequency distribution of migration for graft consolidation groups is shown The probability of cup migration >5mm in case of graft non-consolidation (75%) is significantly larger compared to migration in the presence of a consolidated bone graft (11%) (p=0 008, Fisher's exact test)

Seven clearly migrated cups had reconstructions of a combined segmental/cavitary defect, whereas the 4 remaining migrations occurred in the cavitary defects This means a prob-

Table 5.13. *Data of eleven hips with radiograph type corrected cup migration >5mm (Two re revisions were excluded)*

Primary diagnosis	Graft amount (mm)	Type graft	Defect	Consolidation	Radiolucency (2 or 3 zones)
primary arthritis	33	allograft	combined	+	
primary arthritis	10	allograft	cavitary	+	
secondary arthritis	10	allograft	cavitary	+	
secondary arthritis	30	allograft	cavitary		
secondary arthritis	10	allograft	combined	+	
secondary arthritis	29	allograft	cavitary		+
primary arthritis	6	autograft	combined		+
rheumatoid arthritis	13	autograft	combined	+	+
secondary arthritis	41	allograft	combined	+	
primary arthritis	29	allograft	combined	+	-
secondary arthritis	20	allograft	combined	+	-

Table 5.14. *Frequency distribution of cup migration (> 5 mm) in radiolucency groups (excluded 2 re revisions) Fisher's exact test p=0 03*

	Clear migration	No clear migration
No or 1-zone radiolucency	8 (11%)	64 (89%)
Two or three zone radiolucency	3 (50%)	3 (50%)
Total	11	67

Table 5.15. *Frequency distribution of cup migration (>5mm) in graft consolidation groups (excluded 2 re revisions) Fisher's exact test p=0 008*

Consolidation	Clear migration	No clear migration	Total
No	3 (75%)	1 (25%)	4
Full	8 (11%)	66 (89%)	74
Total	11	67	78

ability of 18% for migration in the combined defect group (table 5 16) The estimated probability of migration in the cavitary defect group amounts to 10% This is not significantly different (p=0 34, Fisher's exact test)

Table 5 17 shows the frequency distribution of cup migration for primary diagnosis groups According to the chi-square test the probability of clear cup migration is possibly not

Table 5.16. *Frequency of cup migration (> 5 mm) in acetabular defect groups (excluded 2 re revisions) Fisher s exact test p=0 34*

Defect type	Clear migration	No clear migration	Total
Cavitary/segmental	7 (18%)	31 (82%)	38
Cavitary	4 (10%)	36 (90%)	40
Total	11	67	78

Table 5.17. *Frequency distribution of cup migration (> 5mm) in primary diagnosis groups (excluded 2 re revisions) Fisher s exact test p=0 08*

Primary diagnosis	Clear migration	No clear migration	Total
Rheumatoid arthritis	1 (11%)	8 (89%)	9
Secondary arthritis	6 (29%)	15 (71%)	21
Primary arthritis	4 (8%)	44 (92%)	48
Total	11	67	78

Table 5.18 *Frequency distribution of cup migration in bone graft groups (excluded 2 re revisions) Fisher s exact test p=1 0*

Type graft	Clear migration	No clear migration	Total
Allograft	9 (14%)	55 (86%)	64
Autograft	2 (14%)	12 (86%)	14
Total	11	67	78

the same for the 3 different primary diagnosis groups Estimated probability is 8% for primary arthritis, 29% for secondary arthritis and 11% for rheumatoid arthritis (p=0 08)

With regard to type of graft used, it could not be established that allografts should lead to significantly more migration compared to autografts as might be expected on biological grounds As shown in table 5 18, probability of clear cup migration in this series is 14% for both autografts and allografts

5.3.5 Graft amount

Mean graft amount in the acetabular reconstructions was 20 mm (range 3 - 42 mm)

5.3.6 Failures and radiographic loosening

Two cups (2%) had been re-revised and were considered definitely failed. One of the re-revisions was due to a recurrent infection. Both failed reconstructions showed full graft consolidation.

Regarding our definition of radiographic loosening, eight patients (10%) showed clear cup migration without radiolucency, three patients (4%) showed clear cup migration in the presence of radiolucency (2 or 3 zones) and three patients (4%) showed radiolucency in 2 or 3 zones without migration. Total percentage of radiographic loosening was 18%. The average follow-up time of the 2 hips that had definitely failed and 14 hips that were radiographically loose, amounted to 6.4 years.

Excluding the infected case, the one aseptic failure and six radiographic loosened cups occurred in the primary arthritis group (14%), six radiographic loosenings in the secondary arthritis group (29%) and two radiographic loosenings in the RA group (22%). According to a chi-squared test there is no significant difference between the primary diagnosis groups with regard to probability of failure or radiographic loosening (p=0.36). Neither a significant difference in probability of failure or radiographic loosening was found between the two defect groups: one aseptic failure and seven radiographic loosenings in combined segmental/cavitary defects (21%) and seven radiographic loosenings in the the cavitary defect group (17%) (p=0.78, Fisher's exact test). Three out of four reconstructions which did not consolidate were radiographic loose (75%), whereas consolidated reconstructions showed one failure and eleven radiographic loosenings (16%). This is a significant difference (p=0.02, Fisher's exact test).

5.4 Discussion

As primary interest of this study was the fate of acetabular reconstructions with impacted morsellized cancellous bone grafts, the study was restricted to the radiographic results of the patient group. Clinical results were not included. Clinical parameters such as pain and limitations of hip function may be due to problems arising from either the femoral or acetabular side and it may be difficult to determine which is responsible. An attendant reason was the absence of preoperative clinical scores in the patient record, which makes interpretation of postoperative hip score unclear.

Reports dealing with restoration of acetabular bone stock, using autologous morsellized cancellous autografts in primary THA with acetabular protrusion (Hastings and Parker 1975, McCollum et al. 1980), gave rise to the use of the same technique with allograft bone and impaction in failed total hip implants with loss of acetabular bone stock.

Graft consolidation and incorporation are the most important prerequisites for successful reconstructions with bone grafts. Observing the radiographs in our study, it appeared that the mode and extent of graft incorporation could not be assessed reliably and reproducibly

Healing at the graft-host junction by clearly delineated bridging trabeculae (consolidation) could be established more accurately It was therefore decided to use only this parameter for assessment of graft healing In this series, three out of the four cases with failed consolidation became radiographic loose Failing graft consolidation has possibly predictive value with regard to radiographic loosening of the acetabular component

As known from several animal experiments, the biological behaviour of autografts, with regard to rate and extent of graft consolidation and incorporation, is superior to allografts (Goldberg and Stevenson 1987, Friedlaender 1987, Heiple et al 1963, Huo et al 1992) Radiologically, a significant difference in consolidation capacity between autografts and allografts could not be observed in this study, as was concluded in several other radiological studies (Olivier and Sanouiller 1991, Fuchs et al 1988) In contrast mean radiographic consolidation time was shorter in allografts compared to autografts, although statistically not significant Graft revitalization is moving like a front from the host bone bed through the graft (Slooff et al 1993, Buma et al 1992) This might explain the longer complete consolidation time for larger amounts of grafts in this study, as was confirmed in another radiological study (Wilson et al 1989) The incorporation process of solid grafts clearly differs from morsellized grafts The latter are completely replaced by new bone without mechanical weakening during the incorporation process, whereas solid cortico-cancellous grafts remain a mixture of viable and non-viable bone, with a great chance of ultimate collaps (Friedlaender 1987, Jasty and Harris 1990, Enneking and Mindell 1991, Young et al 1991)

Roffman et al (1982), Slooff et al (1993) and Schreurs et al (1994) demonstrated in animal experiments complete incorporation of autologous and homologous morsellized cancellous grafts covered with methylmethacrylate cement Morsellized grafts allow easy adaptation to the irregularities of the host bone bed without gap formation, which might explain its high capacity to incorporate The chips must be tightly impacted resulting in a consistent layer Samuelson et al (1988) abandoned the use of bone cement with grafts They feared insufficient initial fixation and cement preventing graft incorporation On the contrary, cement might enhance initial stability (Schreurs et al 1994), although this could not be proven in our study

Some authors state that in the presence of segmental defects, both peripheral and medial, it is necessary to use solid grafts or metallic devices (Gerber and Harris 1986, Ritter and Trancik 1985) Especially peripheral placed grafts should be subject to high compressive and shear forces (Schuller et al 1993) In this series, medial segmental defects were closed with a thin cortico-cancellous shell and peripheral segmental defects of moderate size were reconstructed with only morsellized grafts, covering the superior edge of the cup Failure rate and radiographic loosening did not differ significantly between pure cavitary defects and combined segmental/cavitary defects Although it can not be concluded from this study limitations must be expected in reconstructing larger non-contained peripheral segmental defects These defects don't allow sufficient impaction of the grafts, which is thought important in creating adequate initial cup stability In these defects containment must be added to the grafts A solid graft seems an inadequate solution as Jasty and Harris (1990) reported

They demonstrated graft resorption in 80% of cases after femoral head allografting and radiographic cup loosening in 32% of hips after an average follow-up of 5 9 years Comparable results were reported by Young et al (1991)

Component migration is considered the golden standard of loosening in follow-up studies of total hip replacement Ranawat et al (1980) and Sutherland et al (1982) described their methods of measuring migration in detail Since then many follow-up studies have appeared in which the component migration measurement is described poorly, often without mentioning measurement accuracy We evaluated our radiographs quantitatively with the use of a digitizing tablet, which enabled us to perform more reliable, reproducible measurements As both hip-centered and symphysis centered radiographs had to be assessed and compared, it was necessary to develop for this study a new migration measurement method, which made use of only the unilateral teardrop and Kohler line as reference structures Additional evaluation of the hips in ten patients in which both types of radiographs were made at the same time, enabled us to compare the measurements of the two different types of radiographs

In comparing follow-up series of revision total hip arthroplasty often different criteria for radiographic loosening and failure are used Hips with and without acetabular bone grafting are included in the same series, reconstructions with solid and morsellized bone grafts are not seperated in analysis, types of defects are not comparable and follow-up periods differ Marti et al (1990) reported 6 definite failures (10%) in a series of sixty cemented revisions with an average follow-up of 8 9 years Ten cups (17%) showed radiographic loosening Only 19 of the sixty cups were augmented with a bone graft Olivier and Sanouiller (1991) published the results of 46 cemented cup revisions, augmented with impacted cancellous bone grafts The surgical technique was comparable to our series Average follow-up was only 2 6 years Two definite failures had occurred and two radiographic loosenings Mean graft consolidation time in their series was 7 months This is longer compared to the mean consolidation time of 5 months for autografts and 4 months for allografts in our study Al though best results were achieved in contained cavitary defects, in our study morsellized grafts were equally effective in different types of defects Samuelson et al (1988) used cementless cups with support rings, augmented with morsellized homograft bone in 37 hips Two radiographic loosenings were recorded after an average follow-up of 1 5 years Cementless reconstructions are effective during short-term follow-up (Oakeshott et al 1987, Samuelson et al 1988, Padgett et al 1993) Bone grafts in the presence of a mobile bipolar socket, show a high rate of socket migration and graft resorption (Wilson et al 1989, Brien et al 1990) This supports the hypothesis, that a stable implant is necessary for successful graft incorporation

The series in this study is uniform, regarding surgical technique, method of acetabular reconstruction and aftertreatment All cups were augmented with morsellized bone grafts A strict definition of radiographic loosening was used Cups with radiolucency in 2 or 3 zones without clear migration (3 cups in this series), often called "possible loosening", were considered radiographically loose Two cups (2%) had definitely failed (re-revision) Fourteen cups (18%) were considered radiographically loose, but apparently there had been no indication for re-revision as yet It must be kept in mind that our method of migration measurement with a digitizing tablet offers more accuracy compared to conventional methods as routinely used The failure rate of 2%, including one recurrent infection, and the radiographic loosening percentage of 18% in this series, seem very acceptable in revision arthroplasty

In fact the presented technique offers opportunities in revision hip surgery to create a situation comparable with a primary implant, although it will never be the same.

5.5 Conclusions

Impacted morsellized cancellous auto- and allografts have a high capacity to consolidate in acetabular defects after a failed primary implant A cemented cup supplemented with impacted morsellized cancellous grafts seems to have sufficient initial stability to allow complete graft consolidation Consolidation time depends on graft amount and is not influenced significantly by primary diagnosis or type defect Non-consolidation has possibly negative predictive value for future cup loosening Two percent of reconstructions had definitely failed and 18% of cups showed radiographic loosening after a mean follow-up of 6 4 years Failure rate and radiographic loosening was not influenced by type defect or primary diagnosis Autografts and allografts are equally effective

5.6 Justification

Radiographic evaluation of total hip arthroplasty is only a part of the total assessment It can not simply be transformed into clinical results It is possible that patients with a radiographically loose reconstruction are asymptomatic On the other hand a painfull total hip arthroplasty may show a perfect radiographic picture A bad clinical score might be caused by factors not related to the reconstructed acetabulum and conversely The radiographs in this study provided adequate insight in the behaviour of acetabular components supplemented with morsellized bone grafts, which was the only aim of this study With regard to the above mentioned considerations, the outcome of this study must be interpreted with care Only 2 cups were re-revised during the follow-up period, whereas 14 other cups were evaluated radiographically loose, but not yet re-revised

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CHAPTER 6

General discussion and conclusions

Bone grafts are generally considered the best possible solution nowadays to restore acatabular bone stock defects in the presence of a failed implant (chapter 2). It was not the purpose of this study to perform a comparative study of different bone graft reconstructions, but to evaluate one specific technique in revision of a failed acetabular component.

The radiographic study, with an average follow-up of 5.7 years, shows that impacted morsellized cancellous bone grafts are effective to reconstruct acetabular defects combined with a cemented cup with a failure rate of 2% and radiographic loosening signs in 18% (chapter 5). The strength of the technique is its relative simplicity and general applicability regardless type and size of defect, primary diagnosis or condition of the host bone bed. Success of the reconstruction depends on the mode of graft consolidation. The high capacity of the bone graft to consolidate is probably for the larger part caused by the morsellized cancellous structure and its easy adaptibility to the irregular host bone bed. In contrast to the natural history of auto- and allografts, in which allografts are considered inferior to autografts, radiographically no differences could be observed between these two types of graft regarding speed and extent of consolidation. This is important because of the unlimited quantities of available allograft bone in bone banks. Although not specifically investigated, immunological reactions to allografts seem to be of no clinical importance in this technique. The restored bone stock creates the possibility of a subsequent revision procedure, in case of repeated cup loosening. This is more difficult in the presence of loosened large metallic devices such as custommade prostheses and acetabular support rings.

The histological study of the animal experiment in chapter 3 confirmed the high capacity of allografts in the acetabulum to incorporate. At 12 weeks, allograft reconstructions in the goat showed complete incorporation. Some authors in literature fear the adverse effects of bone cement on graft incorporation. However, possible side effects of bone cement on the incorporation process could not be traced in the radiographic study (chapter 5). Neither could negative influences of bone cement on the incorporation process be established in the histological study (chapter 3). However, it remains uncertain whether cement is responsible for the late loosening events at the cement-graft interface, observed in the animal study. A simultaneous bone apposition and resorption process is observed moving like a revitalization front from the host-bone towards the graft-cement junction. Cup stability is possibly at risk during the incorporation process. Reversely, bone grafts in the presence of an unstable cup will fail to incorporate.

From our loading experiments in the goat during the first 12 weeks (chapter 4) can be concluded that advancing incorporation has a beneficial effect on cup stability. It is hypothesized that the cement and tight impaction of the chip graft are most important in creating sufficient initial cup stability Thereby the graft provides an ideal surface for cement interlock (2-3 mm in the animal experiment).

Histological study in the animal model (chapter 3) at 24 and 48 weeks shows clear signs of micromovements and cup instability as evidenced by a thick, dense fibrous tissue membrane at the bone-cement interface with only some small areas of direct bone-cement contact. Also clinical signs of cup loosening were present in majority of animals and confirmed at sacrifice. This event at the bone-cement interface was a rather consistent finding in the presence of complete graft incorporation In some cases an incomplete thin cement mantle might contribute to this early loosening process, but does not fully explain the whole picture This increasing cup instabilty after 24 weeks evidenced in the histological study, could be confirmed more or less in the loading experiment (chapter 4). At 48 weeks 2 out of 3 animals showed complete failure of the cup with graft resorption The only specimen tested after 48 weeks, without clinical symtoms of loosening, showed significantly more cup motion compared to the specimens tested at 12 weeks. The trend of cup loosening in the animal model, after graft incorporation was achieved, did not correlate with the radiographic findings in the patients. Two cups (2%) had definitely failed and fourteen cups (18%) showed radiographic signs of loosening. Average follow-up for the patients with failure or radiographic looosening was 6.4 years, whereas average follow-up for the whole series was 5.7 years.

The animal model caused some restrictions compared to the human situation The compromised, sclerotic host-bone bed after a failed implant, was not present in our animals since these were primarily operated. The goats were ambulated after 2 days whereas patients kept bedrest for 6 weeks and allowed full weight bearing only 3 months post operatively. On the other hand, the size of the acetabulum in the goats allowed creation of a combined segmental/cavitary defect as often encountered in revision situations The goat is a strong test animal, which loaded the operated leg soon after surgery.

Although it can not be specifically derived from this study, it must be stressed that limitations of the reconstruction technique with morsellized cancellous grafts might be expected on theoretical grounds. Adequate graft containment cannot be achieved in large segmental defects. Whether metallic devices or solid block grafts must be applied in these circumstances remains questionable.

The following conclusions can be drawn from this study:

- Impacted morsellized cancellous allografts have a high capacity to incorporate in acetabular defects, irrespective of defect-type and condition of host-bone bed.
- Radiological incorporation time depends on the amount of bone graft. This can be explained by the histological picture in the animal experiment in which a revitalization front moves from the host-bone bed towards the graft-cement interface with simultaneous bone resorption and apposition.
- Bone cement has no adverse effects on the incorporation of bone allografts in the acetabulum

- Morsellized cancellous autografts and allografts are radiographically equally effective in acetabular reconstruction
- Initial cup stability is sufficient to allow complete graft incorporation In the goat, during the process of graft incorporation in the first 12 weeks, cup stability increases
- In the goat at 24 and 48 weeks cup instability is encountered as shown by a thick fibrous tissue interface at the graft-cement junction and a high percentage of cup loosening at sacrifice
- Radiographic results in the patient study are better than might have been expected from the animal experiment, with a failure rate of 2%, needing re-revision, and radiographic loosening signs in 18% The restoration of bone stock provides an adequate bone bed in case of subsequent revision in the future

Summary

Primary total hip arthroplasty (THA) is generally considered a successful procedure. However, aseptic loosening of the implant remains the most important long-term complication. The loosening process is accompanied by damaging and loss of surrounding bone stock to a more or lesser extent. In last decades several methods for revision have been described. In this thesis some aspects of a specific revision technique for the acetabular component are described, in which bone stock defects are reconstructed with impacted morsellized cancellous bone grafts, combined with a cemented acetabular cup.

Chapter 2 presents a review of the literature about biological and biomechanical properties of the different types of bone grafts. The sequence of events during the incorporation process is equal for autografts and allografts, but the rate and extent of incorporation is in favour of autografts. In general cancellous bone is completely incorporated. Cortical grafts remain an admixture of viable and necrotic bone with, as a consequence, a decrease in mechanical strength. Morsellized cancellous bone grafts (chips) are mostly completely incorporated, without temporary mechanical weakening, in contrast to solid cortico-cancellous bone. A review of the literature is presented about different reconstruction techniques for acetabular defects with bone grafts. The use of allograft bone is generally accepted. Segmental peripheral rim defects are reconstructed preferably with solid cortico-cancellous bone blocks with screw fixation. Most authors prefer reconstruction of segmental medial wall defects with cortico-cancellous shells, together with a metallic support device. Cavitary defects, with intact acetabular continuity, are mostly restored with morsellized cancellous bone grafts, whether or not impacted. No unanimity exists about cemented or cementless implant fixation.

In chapter 3 an animal experiment with goats is described. In these animals an acetabular defect was created and reconstructed with impacted morsellized cancellous allografts, whereafter a cemented total hip arthroplasty was performed. The purpose was to be informed about the rate and extent of graft consolidation and incorporation and developments at the interface between graft and cement during incorporation process. The test animals were sacrificed after 0, 3, 6, 12, 24 and 48 weeks, followed by histological examination. Consolidation between graft and host bone was already observed after 3 weeks. Incorporation showed a rather consistent pattern. Simultaneous resorption of graft bone and apposition of new bone was observed during the first twelve weeks. After this period the original graft had nearly completely disappeared and was replaced by viable, reorganized trabecular bone. At the interface between bone and cement local contact areas of viable bone and cement were seen, next to areas with fibrous tissue interposition. After longer follow up progressive fibrous interface formation developed with wear particles and loosening of the implant It was concluded that morsellized cancellous bone grafts, combined with a cemented cup, have a high capacity to consolidate and incorporate In this animal model, long-term observation (24 and 48 weeks) showed frequent aseptic loosening

Chapter 4 deals with a loading experiment The purpose of this experiment was to be informed about the stability of an acetabular cup augmented with bone grafts, initially after the operation and its course in time The same animal model, described in chapter 3 was used The goats were sacrificed direct post operatively and after 3, 12 and 48 weeks After explantation of the reconstructed acetabulum graft incorporation was assessed radiographically The cups were loaded in a testing machine to 700 Newton Translations and rotations of the cup relative to bone were measured using roentgen stereophotogrammetry A decrease in translations was observed from direct post-operative to 12 weeks The same trend, although less consistent, was observed for rotations Maximum translation and rotation direct post-operative amounted 0 57 mm and 3 0 degrees respectively In the 12 weeks group these values had decreased to 0 16 mm and 2 0 degrees respectively In the 48 weeks group only one specimen could be tested The remaining two specimens showed at sacrifice complete loosening of the cups with severe bone stock loss At 12 weeks full graft incorporation was observed From this experiment could be concluded that acetabular cups, augmented with chip allografts, show increasing stability up to 12 weeks, with radiographic graft incorporation at 12 weeks Graft incorporation has a benficial effect on cup stability In this animal model, a high chance of aseptic cup loosening is observed after 48 weeks

Results of revising a loosened acetabular cup with the described technique are presented and analyzed in chapter 5 A retrospective radiological study was performed of 80 reconstructions in 80 patients with an average age of 58 years (23 - 81 years) Average follow-up was 5 7 years (2 0 - 10 9 years) Two cups (2%) were re revised, one cup due to recurrent infection Radiographic loosening signs were observed in 14 (18%) of the remaining cups Median consolidation time was 0 42 years and 0 30 years for autografts and allografts respectively (p=0 39) Consolidation time was also dependent on graft amount In 4 reconstructions graft consolidation was not present No significant difference was observed between autografts and allografts with regard to failing graft consolidation Failing graft consolidation has possibly predictive value for radiographic loosening Type of defect and primary diagnosis did not have predictive value for cup failure or radiographic loosening Autografts showed more radiolucency compared to allografts (p=0 008) This was not the case for cup migration The radiographic results were considered fair for revision hip surgery Bone bed repair was nearly always achieved which is considered important for possible subsequent revision in future

Samenvatting

De primaire totale heuparthroplastiek wordt algemeen als een succesvolle procedure beschouwd Desondanks blijft aseptische loslating van het implantaat de belangrijkste lange termijn complicatie Het loslatingsproces wordt begeleid door beschadiging en verlies van omgevend bot in meer of mindere mate De afgelopen decennia zijn diverse revisiemethoden beschreven In dit proefschrift worden diverse aspecten beschreven van een specifieke revisietechniek voor de acetabulaire component, waarbij de ossale defecten worden gereconstrueerd met geïmpacteerde spongieuze botchips in combinatie met cementfixatie van de acetabulaire cup

Hoofdstuk 2 geeft een overzicht van de literatuur omtrent de biologische en biomechanische eigenschappen van de verschillende typen bottransplantaten De opeenvolgende stadia van het incorporatie proces zijn aanwezig zowel bij autologe als homologe transplantaten, waarbij de snelheid en mate van incorporatie in autoloog bot groter is Spongieus bot wordt in het algemeen volledig geïncorporeerd Daarentegen blijven corticale transplantaten een mengsel van vitaal en necrotisch bot, hetgeen een vermindering van mechanische sterkte tot gevolg heeft Gefragmenteerde spongieuze bottransplantaten (chips) leiden meestal tot complete incorporatie, zonder tijdelijke mechanische verzwakking, in tegenstelling tot solide cortico-spongieus bot Verder wordt een literatuuroverzicht gegeven van de verschillende reconstructietechnieken van acetabulaire defecten met bottransplantaten Het gebruik van homoloog bot is algemeen geaccepteerd Perifere randdefecten worden bij voorkeur gereconstrueerd met solide cortico-spongieuze botblokken met schroeffixatie Mediale wanddefecten worden door de meeste auteurs gesloten met cortico-spongieuze botspanen in combinatie met een metalen ondersteuningsring Holtevormige defecten waarbij de continuiteit van het acetabulum niet is verstoord, worden meestal opgevuld met spongieuze botchips, al dan niet geïmpacteerd Er bestaat geen eenstemmigheid omtrent gecementeerde of cementloze implantaatfixatie

In hoofdstuk 3 wordt een dierexperimentele studie beschreven met geiten In deze dieren werd een acetabulair defect gecreeerd en gereconstrueerd met geïmpacteerde homologe spongieuze botchips, waarna een gecementeerde totale heup arthroplastiek werd verricht Het doel was inzicht te krijgen in de mate en snelheid van consolidatie en incorporatie van het transplantaat en de ontwikkelingen in de overgangszone tussen cement en transplantaat tijdens het incorporatieproces De proefdieren werden geofferd na 0, 3, 6, 12, 24 en 48 weken, waarna histologisch onderzoek plaatsvond Consolidatie tussen transplantaat en gastheer werd reeds na 3 weken waargenomen Incorporatie verliep volgens een consistent patroon Resorptie van transplantaatbot en appositie van nieuw bot werden gelijktijdig gezien gedurende de eerste 12 weken Na deze periode was het oorspronkelijke transplantaat bijna geheel vervangen door vitaal, gereorganiseerd lamellair bot. In de overganszone tussen bot en cement werd plaatselijk contact tussen vitaal bot en cement gezien, naast gebieden met weke delen interpositie. Na langere follow-up werd toenemende weke delen interpositie met slijtage partikels gevonden met loslating van het implantaat. Geconcludeerd wordt dat homologe botchips in combinatie met een gecementeerde acetabulaire cup een groot vermogen tot consolidatie en incorporatie vertonen. Op langere termijn (24 en 48 weken) treedt in dit diermodel frequent aseptische loslating op.

Hoofdstuk 4 beschrijft een belastingsexperiment, waarmee getracht werd inzicht te krijgen in de stabiliteit van de acetabulaire component direct postoperatief en in het verloop van de tijd. Hiervoor werd gebruik gemaakt van hetzelfde diermodel als in hoofdstuk 3. De geiten werden direct postoperatief geofferd en na 3, 12 en 48 weken. Na explantatie van het gereconstrueerde acetabulum werd radiologisch de mate van incorporatie bepaald. De cups werden belast op een drukbank tot maximaal 700 Newton. Translaties en rotaties van de cup ten opzichte van het omgevende bot werden gemeten middels rontgen-stereofotogrammetrie. Van 0 tot 12 weken werd een afname geconstateerd in translaties. Dezelfde trend, alhoewel minder consistent, werd gevonden voor de rotaties. Maximale translatie en rotatie direct postoperatief bedroegen respectievelijk 0.57 mm en 3.0 graden. Bij de 12 weken groep was dit gedaald tot respectievelijk 0.16 mm en 2.0 graden. Van de 48 weken groep kon maar een acetabulum worden getest. De overige twee preparaten toonden bij offeren complete loslating met ernstig botverlies. Na 12 weken werd volledige graftincorporatie gezien. Uit dit experiment kon worden geconcludeerd dat acetabulaire cups, geaugmenteerd met homologe botchips, vanaf direct postoperatief tot 12 weken toenemende stabiliteit vertoonden met radiologisch incorporatie van het bottransplantaat na 12 weken. Incorporatie van het transplantaat heeft een gunstig effect op de cupstabiliteit. Op het tijdstip 48 weken is in dit diermodel sprake van een grote kans op opgetreden loslating.

De resultaten van revisie van een loszittende acetabulaire component met behulp van de beschreven techniek worden weergegeven en geanalyseerd in hoofdstuk 5. Het betreft een retrospectieve radiologische studie van 80 reconstructies bij 80 patienten met een gemiddelde leeftijd van 58 jaar (23 - 81 jaar). De gemiddelde follow-up was 5.7 jaar (2.0 - 10.9 jaar). Twee cups (2%) dienden te worden gerereviseerd, waarvan een cup als gevolg van een recidief infect. Tekenen van radiologische loslating werden vastgesteld bij 14 (18%) van de overige acetabulum cups. Mediane consolidatietijd was 0.42 jaar en 0.30 jaar voor respectievelijk autologe en homologe transplantaten (p=0.39). De consolidatieduur bleek mede afhankelijk van de hoeveelheid transplantaat. In 4 reconstructies werd geen consolidatie van het transplantaat waargenomen. Er was geen significant verschil tussen autologe en homologe transplantaten met betrekking tot falende consolidatie. Falende consolidatie heeft mogelijk voorspellende waarde voor het ontstaan van radiologische loslating. Er werd geen significant verschil gevonden tussen verschillende defecttypen met betrekking tot falen of radiologische loslating. Ook de diagnose waaronder de primaire totale heuparthroplastiek werd verricht bleek niet van invloed. Autologe transplantaten bleken een hogere kans te geven op radiolucentie dan allografts (p=0.008). Dit gold niet voor cupmigratie. De radiologische resultaten kunnen als zeer acceptabel worden beschouwd voor revisie heup chirurgie. Er is een grote kans op herstel van het botbed, hetgeen van belang is voor een eventuele nieuwe revisieprocedure in de toekomst.

Appendix

Table 1

Table 1.a. *Translations (mm) along medial-lateral (X) axis after loading and subsequent unloading.*

goat	700N 10min	0N 10min
56LB	-0.405	-0.065
57LB	-0.924	0
59LB	-0.711	-0.185
69B	-0.575	-0.120
70B	-0.034	-0.004
75B	-0.464	-0.053
81B	-0.279	-0.010
82B	-0.095	-0.029
88B	-1.341	-0.602
56RB	-0.336	0.073

Table 1.b. *Translations (mm) along cranio-caudal (Y) axis after loading and subsequent unloading.*

goat	700N 10min	0N 10min
56LB	1.052	0.347
57LB	0.936	0
59LB	1.352	0.572
69B	0.405	0.076
70B	0.543	0.228
75B	0.142	0.053
81B	0.268	0.095
82B	0.059	-0.028
88B	1.436	0.802
56RB	1.338	0.509

Table 1.c. *Translations (mm) along dorso-ventral (Z) axis after loading and subsequent unloading*

goat	700N 10min	0N 10 min
56LB	0 641	-0 106
57LB	0 868	0
59LB	-1 051	-0 267
69B	1 069	-0 250
70B	-1 223	0 375
75B	-0 299	-0 007
81B	-0 078	0 056
82B	0 460	0 161
88B	-2 366	-1 073
59RB	-0 194	-0 118

Table 1.d. *Translation resultants (mm) after loading and subsequent unloading*

goat	700N 10min	0N 10min
56LB	1 297	0 369
57LB	1 576	0
59LB	1 854	0 658
69B	1 280	0 288
70B	1 339	0 439
75B	0 570	0 075
81B	0 395	0 111
82B	0 473	0 166
88B	3 075	1 469
59RB	1 393	0 528

Table 1.e. *Rotations (degrees) around medial-lateral (X) axis after loading and subsequent unloading*

goat	700N 10min	0N 10min
56LB	-2.64	-0.9
57LB	-3.46	0
59LB	-6.00	-2.97
69B	0.26	2.07
70B	-1.31	-0.73
75B	0.10	0.31
81B	-0.24	-0.82
82B	-0.44	-0.18
88B	6.00	1.09
56RB	-0.12	-0.53

Table 1.f. *Rotations (degrees) around cranio-caudal (Y) axis after loading and subsequent unloading*

goat	700N 10min	0N 10min
56LB	-2.71	-0.57
57LB	-0.98	0
59LB	-3.34	-0.09
69B	0.34	-2.45
70B	0.51	0.58
75B	-0.93	0.27
81B	-0.19	0.61
82B	-0.30	0.46
88B	-1.81	-2.80
56RB	-0.59	-0.23

Table 1.g. *Rotations (degrees) around dorso-ventral (Z) axis after loading and subsequent unloading*

goat	700N 10min	0N 10min
56LB	1.50	0.73
57LB	1.08	0
59LB	1.78	0.89
69B	0.26	-2.29
70B	0.53	0.36
75B	0.20	-0.06
81B	-0.73	-0.51
82B	-2.25	-2.03
88B	-3.59	-1.90
56RB	-2.86	-1.66

Table 2 *Observations in 80 patients in the radiologic study*

a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p
patient	age	sex	side	diagn	defect	g.type	g.amount	fol.up	cons.t	r.luc.s	r.luc.a	r.luc.m	migr.s	migr.m	rerev.cup
1	27	M	L	SEC	COMB	AUTO	21	10.0	0.2	NO	NO	NO	1	1	NO
2	34	F	R	PRIM	COMB	ALLO	22	4.1	0.5	NO	NO	NO	1	2	NO
3	50	F	L	PRIM	CAV	ALLO	9	4.5	0.2	NO	NO	NO	1	1	NO
4	29	M	R	PRIM	CAV	AUTO	8	8.1	0.3	NO	NO	NO	3	0	NO
5	51	F	L	PRIM	CAV	AUTO	17	7.7	0.2	YES	NO	YES	2	3	NO
6	47	F	R	SEC	COMB	ALLO	22	4.5	1.0	NO	NO	NO	1	0	NO
7	23	F	L	PRIM	COMB	ALLO	24	9.4	0.7	NO	NO	NO	2	2	NO
8	54	F	L	PRIM	COMB	ALLO	18	5.2	0.3	NO	NO	NO	3	2	NO
9	31	F	R	SEC	CAV	AUTO	17	7.0	0.6	NO	NO	NO	2	2	NO
10	80	F	L	PRIM	COMB	ALLO	33	8.7	0.3	NO	NO	NO	5	6	NO
11	72	F	R	SEC	COMB	ALLO	14	3.3	0.3	NO	NO	NO	1	1	NO
12	63	F	L	PRIM	CAV	ALLO	10	3.2	0.3	NO	NO	NO	11	1	NO
13	66	F	R	SEC	COMB	ALLO	32	5.1	1.1	NO	NO	YES	3	1	NO
14	35	F	R	RA	COMB	AUTO	21	3.7	(1.8)	NO	NO	NO	1	0	NO
15	71	M	L	PRIM	CAV	ALLO	22	3.8	1.0	NO	NO	NO	5	1	NO
16	40	M	R	SEC	CAV	ALLO	19	5.7	0.3	NO	NO	NO	2	1	NO
17	72	F	L	SEC	CAV	ALLO	10	7.2	0.3	NO	NO	NO	6	1	NO
18	59	F	L	PRIM	CAV	ALLO	9	9.5	0.3	NO	NO	NO	3	2	NO
19	53	F	R	PRIM	COMB	ALLO	30	6.2	0.2	NO	NO	NO	1	1	NO
20	69	F	L	PRIM	COMB	AUTO	21	9.5	0.6	YES	YES	YES	3	3	NO
21	60	F	L	PRIM	CAV	ALLO	28	4.8	0.3	NO	NO	YES	1	1	NO
22	62	F	L	PRIM	CAV	ALLO	20	5.5	0.3	NO	NO	NO	2	3	NO
23	64	F	L	PRIM	CAV	ALLO	13	4.9	0.5	NO	YES	NO	2	1	NO
24	38	F	R	RA	COMB	ALLO	24	6.1	0.2	NO	NO	NO	2	1	NO
25	59	F	L	SEC	CAV	ALLO	23	5.1	0.6	NO	NO	NO	2	2	NO
26	79	F	R	SEC	COMB	ALLO	22	3.2	(>3.1)	NO	NO	NO	1	2	NO
27	43	M	L	PRIM	CAV	ALLO	24	3.5	0.3	NO	NO	NO	3	1	NO
28	55	M	L	SEC	CAV	ALLO	30	5.1	(>5.2)	NO	YES	NO	9	2	NO
29	70	M	L	SEC	COMB	ALLO	10	5.8	0.3	NO	NO	YES	3	9	NO
30	59	F	L	RA	COMB	AUTO	30	3.8	0.9	NO	NO	NO	4	2	NO
31	56	F	L	SEC	COMB	ALLO	3	2.2	0.3	NO	NO	NO	1	1	NO
32	62	F	L	PRIM	CAV	ALLO	16	8.6	0.3	NO	NO	NO	2	3	NO
33	39	F	L	SEC	CAV	ALLO	29	5.7	(>5.7)	YES	YES	YES	9	2	NO
34	73	F	R	PRIM	COMB	ALLO	25	3.1	0.4	NO	NO	NO	2	0	NO
35	69	F	R	PRIM	COMB	ALLO	27	5.4	0.4	NO	NO	NO	2	1	NO
36	72	F	R	PRIM	COMB	AUTO	6	8.9	(>8.9)	YES	YES	YES	8	2	NO
37	56	F	R	PRIM	CAV	ALLO	14	4.4	0.3	NO	NO	NO	4	1	NO
38	75	M	R	PRIM	COMB	ALLO	7	5.0	0.3	NO	NO	NO	2	3	NO
39	56	M	L	RA	CAV	AUTO	7	10.9	0.3	YES	NO	NO	5	2	NO
40	39	M	L	SEC	CAV	AUTO	42	2.6	0.4	NO	NO	NO	4	2	YES
41	66	F	R	RA	COMB	AUTO	13	8.9	0.5	YES	YES	YES	9	10	NO
42	75	F	R	PRIM	COMB	ALLO	28	6.2	0.3	NO	NO	NO	3	2	NO
43	60	M	L	PRIM	CAV	ALLO	9	3.8	0.3	NO	NO	NO	2	2	NO
44	61	M	R	PRIM	CAV	ALLO	12	5.0	0.2	NO	NO	NO	2	1	NO
45	35	M	R	RA	CAV	ALLO	12	6.1	0.3	YES	NO	YES	1	1	NO
46	74	F	R	PRIM	COMB	ALLO	27	4.7	0.8	NO	NO	NO	2	2	NO
47	71	F	R	PRIM	COMB	ALLO	30	2.8	0.1	NO	NO	NO	1	2	NO
48	30	F	L	RA	COMB	ALLO	22	5.8	0.3	NO	NO	NO	0	0	NO
49	50	M	L	SEC	COMB	ALLO	41	5.9	1.2	YES	NO	NO	8	5	NO
50	46	M	L	SEC	COMB	ALLO	22	5.3	0.3	NO	NO	NO	3	2	NO
51	45	F	L	PRIM	COMB	ALLO	14	4.1	0.3	NO	NO	NO	1	2	NO
52	44	M	R	SEC	CAV	ALLO	10	5.1	0.3	NO	NO	NO	2	2	NO
53	36	F	L	SEC	CAV	ALLO	25	6.0	0.5	NO	NO	NO	3	4	NO
54	69	F	R	PRIM	COMB	ALLO	36	3.1	0.8	NO	NO	NO	2	2	NO
55	80	F	R	PRIM	CAV	ALLO	28	6.1	1.1	NO	NO	NO	1	2	NO
56	61	F	R	RA	CAV	ALLO	19	7.2	0.2	NO	NO	NO	3	3	NO

Table 2 *Observations in 80 patients in the radiologic study (continued)*

a patient	b age	c sex	d side	e diagn	f defect	g g.type	h g.amount	i fol.up	j cons.t	k r.luc.s	l r.luc.a	m r.luc.m	n migr.s	o migr.m	p rerev cup
57	61	M	L	RA	CAV	AUTO	19	3.0	0.5	NO	NO	NO	2	2	NO
58	61	F	L	PRIM	COMB	ALLO	29	7.2	0.2	NO	NO	NO	1	2	NO
59	65	M	L	SEC	CAV	ALLO	17	3 5	0.1	NO	NO	NO	3	3	NO
60	41	M	L	PRIM	CAV	ALLO	6	5.1	0.3	NO	NO	NO	3	2	NO
61	53	F	R	PRIM	COMB	AUTO	19	9.8	0.8	NO	NO	NO	5	2	NO
62	53	M	L	SEC	CAV	AUTO	22	8.8	0 2	NO	NO	NO	1	2	NO
63	61	F	R	PRIM	COMB	ALLO	37	5.0	0.8	YES	NO	NO	5	2	NO
64	65	F	L	PRIM	CAV	ALLO	13	6.8	0.2	NO	NO	NO	2	3	NO
65	55	F	L	PRIM	CAV	ALLO	17	4.8	0.3	NO	NO	YES	3	1	NO
66	70	F	R	PRIM	CAV	ALLO	11	5.0	0 6	NO	NO	NO	3	1	NO
67	75	F	R	PRIM	CAV	ALLO	25	6.0	0.9	NO	NO	NO	3	0	NO
68	74	F	R	PRIM	COMB	ALLO	24	6.5	0.2	NO	NO	YES	2	3	NO
69	65	F	R	PRIM	COMB	ALLO	29	3.9	0.7	NO	NO	YES	10	4	NO
70	81	F	R	PRIM	CAV	ALLO	8	1 9	0.2	NO	NO	NO	3	5	NO
71	68	F	L	PRIM	CAV	ALLO	6	4.9	0.3	NO	NO	NO	2	4	NO
72	67	F	R	PRIM	COMB	ALLO	18	7.1	1.5	NO	NO	NO	3	1	NO
73	73	F	L	PRIM	COMB	ALLO	19	4.6	0 4	NO	NO	NO	3	3	NO
74	54	M	L	SEC	CAV	ALLO	42	8 7	0 8	NO	NO	NO	3	2	NO
75	75	F	R	PRIM	COMB	ALLO	31	3.2	0.3	NO	NO	NO	2	4	NO
76	59	F	L	SEC	COMB	ALLO	20	6.7	0.3	NO	NO	NO	6	2	NO
77	57	F	L	PRIM	CAV	AUTO	21	8 4	0.8	NO	YES	NO	2	1	NO
78	53	F	L	PRIM	CAV	ALLO	32	5 2	1 1	NO	NO	NO	13	3	YES
79	69	F	R	PRIM	CAV	ALLO	25	5.1	0.2	NO	NO	NO	3	1	NO
80	65	M	R	PRIM	CAV	ALLO	4	4 3	0.3	NO	NO	NO	2	3	NO

a Patient
b Age (years)
c Sex
- female (F)
- male (M)

d Side
- left (L)
- right (R)

e Primary diagnosis
- primary osteoarthritis (prim)
- secondary osteoarthritis (sec)
- rheumatoid arthritis (RA)

f Type defect
- combined cavitary/segmental (comb.)
- cavitary (cav)

g Type graft
- autograft (auto)
- allograft (allo)

h Graft amount (mm)
i Follow-up time (years)
j Consolidation time (years)
k Radiolucency in superior zone ≥ 2mm
l Radiolucency in axial zone ≥ 2mm
m Radiolucency in medial zone ≥ 2mm
n Cup migration in superior direction (mm)
o Cup migration in medial direction (mm)
p Re-revision cup

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Curriculum vitae

Johan Willem Schimmel werd op 8 juni 1957 geboren te Apeldoorn Hij doorliep de Koninklijke Scholengemeenschap aldaar en in 1975 werd het VWO diploma behaald In datzelfde jaar startte hij de studie Scheikunde aan de Rijksuniversiteit te Utrecht In 1976 werd de studie Geneeskunde aangevangen aan dezelfde Universiteit Het artsexamen werd in 1983 afgelegd Vanaf juli 1983 tot september 1984 was hij werkzaam als assistent-geneeskundige niet in opleiding op de afdeling algemene chirurgie van het Catharina Ziekenhuis te Eindhoven Van september 1984 tot juli 1988 was hij werkzaam als assistent-geneeskundige in voor-opleiding algemene chirurgie in het Diaconessenhuis te Hilversum (J H Kroesen, wijlen Dr F L R Bauer en Dr J W Juttmann) Van juli 1988 tot april 1993 was hij werkzaam op de afdeling orthopaedie van het Academisch Ziekenhuis Nijmegen St Radboud waarvan de laatste 4 jaar in opleiding tot orthopaedisch chirurg (opleiders Prof Dr T J J H Slooff en Prof Dr R P H Veth) Op 1 april 1993 vond inschrijving in het specialisten register plaats Sindsdien is hij werkzaam als orthopaedisch chirurg in het Medisch Centrum Leeuwarden in associatie met de orthopaedisch chirurgen Dr J Rijnks, Dr J F A M Ypma, Drs W de Graaf, Dr W H J Kok en de aldaar gevestigde algemeen chirurgen, plastisch chirurgen en urologen Hij is gehuwd met Isa ten Kate,biologe, en zij hebben twee kinderen Cecile en Feiko

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STELLINGEN

behorende bij het proefschrift

Acetabular reconstruction with impacted morsellized cancellous bone grafts in cemented revision hip arthroplasty

J.W. Schimmel

Nijmegen, 10 november 1995

I Acetabulair botverlies bij implantaat loslating kan adequaat worden gereconstrueerd met geimpacteerde homologe spongieuze botchips (dit proefschrift)

II Radiologisch kan er geen verschil in effectiviteit worden geconstateerd tussen autologe en homologe spongieuze botchips bij reconstructie van acetabulaire botdefecten (dit proefschrift)

III Botcement heeft geen nadelige invloed op de incorporatie van spongieuze botchips (dit proefschrift)

IV Progressief botverlies rond een totale heupprothese zonder pijnklachten vormt een indicatie voor een revisieprocedure

V Er dienen internationaal geldende richtlijnen te worden opgesteld voor follow up studies van totale heuparthroplastieken teneinde de vergelijkbaarheid te bevorderen

VI Primaire stabiliteit van cementloze totale heupprothesen berust op slechts enkele lokale contactgebieden tussen prothese en bot (J W Schimmel en R Huiskes Acta Orthop Scand 59, 638-642, 1988)

VII Arthroscopische nettoyage van een arthrotisch gewricht is slechts van beperkte waarde en de indicatie hiervoor dient spaarzaam te worden gesteld

VIII Het is niet juist de vrijgevestigde medisch specialist nog langer als vrije beroepsbeoefenaar te beschouwen

IX Communicatie tussen verschillende disciplines wordt vaak bemoeilijkt door niet-overeenkomende vaktaal

X Uit historisch oogpunt is het correcter de naam van de provincie Friesland te veranderen in Vrieslandt in plaats van Fryslân

XI Uit het oogpunt van natuurbehoud dient het omzetten van eentonige graslanden in bloemrijke hooilanden door aanpassing van de agrarische bedrijfsvoering te worden gestimuleerd en beloond

XII De antropomorfologische overeenkomst tussen orthopaedisch chirurgen en volwassen gorilla's beperkt zich tot gelijke gemiddelde handomvang (J S Fox et al Are orthopaedic surgeons really gorillas? Br Med J 301 1425 - 1426 1990)